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DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

Technical Report 1727-TR

INVESTIGATION OF CALOTTAN SHEET STIFFENING PROCESS

Task 8S93-31-001-08
(formerly Project 8-93-31-400)

24 October 1962

U. S. Army
Engineer Research And
Development Laboratories

FORT BELVOIR, VIRGINIA

AD ________ Accession No. ________

U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia - INVESTIGATION OF CALOTTAN SHEET STIFFENING PROCESS - George D. Farmer, Jr. and William B. Spangler

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Distributed by

The Commanding Officer
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Prepared by

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Fort Belvoir, Virginia

PREFACE

Authority for the investigation covered in this report is contained under Task 8S93-31-001-08, "Application of Lightweight Metals in Engineer Equipment." A copy of the task card is included as Appendix A to this report. The investigation of patterns for stiffening sheet materials is part of the effort to increase the mobility and decrease the weight of Engineer equipment by devising means for utilizing metals more efficiently in the equipment.

The work was conducted by George D. Farmer, Jr. assisted by Robert C. Mifflin, under the direction of William B. Spangler, Chief of Metallurgy and Materials Conservation Section, and Arthur W. Van Heuckeroth, Chief of Materials Branch. The vibration frequency tests were made by F. J. Lindner, Jr. and F. Stowell of the Packaging Development Branch.

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GLOSSARY OF TERMS

Definitions of some of the terms as used in this report are given here for clarity. Definitions are arranged in alphabetic order.

CALOTTAN. The trade name used by its developers for a process for increasing the stiffness of sheet materials without increasing their weight by forming the sheet into a stiffening pattern of calottes.

Calotte. *Websters New International Dictionary* defines calotte as "a close cap without visor or brim; a plain skullcap." The term as used by the developers of the CALOTTAN process and in this report indicates an area of sheet material formed into either a hollow hemisphere or a hollow segment of a sphere atop the frustrum of a hollow cone.

Calotte height. The height (or depth of a concave calotte) of the top of the calotte measured from and normal to the flat surface of the original sheet.

Calottized. Indicates a sheet that has been stiffened by forming into the CALOTTAN stiffening pattern of calottes.

Calottizing. The operation of stiffening a sheet by forming it into the CALOTTAN stiffening pattern of calottes.

Key Unit. An arrangement of six calottes which is the base controlling the location of all the calottes in the CALOTTAN stiffening pattern.

Module. The length of a side of the square pattern of calottes which is repeated as required to calottize a sheet material.

Optimum calotte height. The calotte height producing the greatest rigidity in a sheet of a specific material and thickness.

Optimum calottizing. The operation of stiffening a sheet by forming it into a CALOTTAN stiffening pattern of optimum height calottes.

Percentage calottized. The calotte height of a particular sheet expressed as a percentage of the height of a full hemispherical calotte.

Rigidity. The bending strength of a sheet when tested as a simple beam. The word is used in this sense because of its acceptance commercially in referring to "rigidized" sheet.

Stiffness. Same as rigidity.

SUMMARY

This investigation revealed that metallic sheet materials when cold formed in the CALOTTAN stiffening pattern show increased rigidity and impact resistance worth considering in equipment design. However, this pattern like all stiffening patterns known to the authors displays preferred axes of rigidity. The investigation also showed that rigidized metallic sheet available in the United States from X Company is approximately as efficient as calottized sheet.

The report concludes that:

a. The rigidity and impact resistance of sheet materials are increased considerably by calottizing.

b. The claim made by CALOTTAN representatives that the rigidity of sheet materials is increased ten times by calottizing is considered valid for only the thinnest sheet of the range that can be formed in the CALOTTAN die.

c. The representatives of CALOTTAN are not familiar with the properties of rigidized sheet produced by X Company. Their claim that calottized sheet has "rigidity many times greater than that of any known material of this type" is not considered valid because sheet rigidized by the X Company pattern shows stiffness approximating that of similar calottized sheet.

d. Calottized metallic sheet displays preferred axes of rigidity, so the claim made by CALOTTAN representatives that calottized sheet has "no preferred axes of inertia" is not considered valid.

e. Rigidized metallic sheet materials can be used to reduce the weight of some components of Military equipment.

f. Calottized metallic sheet should be considered by designers of Military equipment on a value analysis basis when calottized sheet becomes available in the United States.

g. Rigidized sheet produced in the United States by X Company is approximately as efficient as calottized sheet, is presently available in the United States, and should be considered by designers of Military equipment on a value analysis basis.

INVESTIGATION OF CALOTTAN SHEET STIFFENING PROCESS

I. INTRODUCTION

1. Subject. This report covers an investigation of CALOTTAN, a process for increasing the rigidity of sheet materials without increasing their weight by forming the sheet into a stiffening pattern of calottes. Figure 1 shows metal sheet rigidized by the CALOTTAN process.

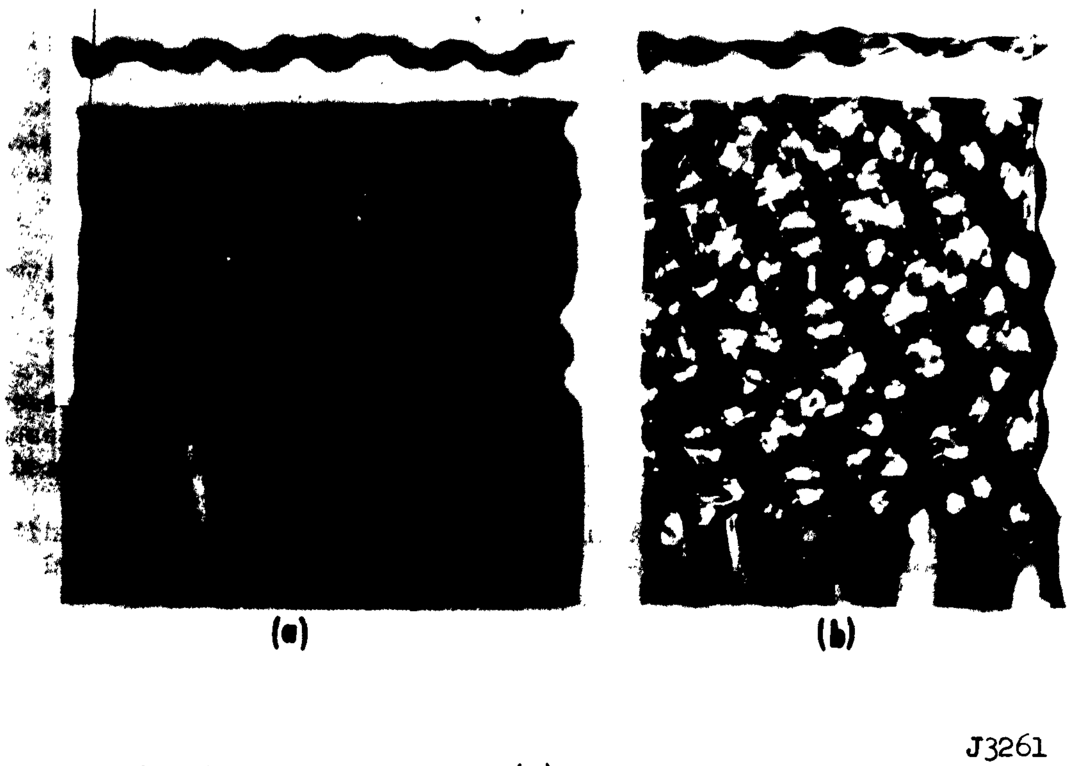

Fig. 1. Calottized sheet: (a) 75 percent calottized; (b) optimum calottized.

The requirements for lighter Military equipment and structures make it imperative that we know and exploit all the properties of materials so our designs can utilize materials at maximum efficiency. The possibility of improving their properties by forming patterns in metal sheet appeared promising and not completely developed. One process which showed promise but with limitations was what is commonly known in this country as "rigidizing," that is,

stiffening. Several stiffening patterns exist. However, the representatives of a stiffening process called "CALOTTAN" (U. S. Patent No. 2,738,297 (Appendix B), dated 13 March 1956), make some strong and interesting claims, such as, rigidity of sheet increased by 1,000 percent over flat sheet and "no preferred axes of inertia." It appeared there should be important Military applications for sheet of such increased rigidity, particularly if they had no axes of weakness. Because engineering data had not been developed and none of the sheet rigidized by calottizing was available commercially, a release agreement was obtained (Appendix C), and the experimental production and evaluation reported herein were undertaken to determine if the claims for the CALOTTAN process (par. 3) are valid and to provide some engineering data.

2. Background and Previous Investigation. The background is limited to information obtained from the various patents covering sheet stiffening patterns which were studied and information as to the stiffening effect of these patterns contained in published data and articles and furnished by manufacturers utilizing the patterns for their product.

Previous investigation by these Laboratories was a limited study of the effect of the CALOTTAN stiffening pattern on plastic sheet. This work done by the Plastics Section, Materials Branch, under Project 8-93-31-400, is reported in Materials Branch Report No. 6126-3, dated 15 October 1958 and titled, "Effect of an Embossed Pattern on the Rigidity of Plastics." This report found that "assuming a rigidity of 1 (one) for the unembossed sheet, a single formed sheet had a rigidity of 6.3; two molded sheets face to face, a rigidity of 14.0; two molded sheets face to face bonded, a rigidity of 25.0; and two molded sheets face to face with pattern matched and bonded, 44.0. No zones or axes of weaknesses were found."

II. INVESTIGATION

3. Patent and Literature Search. A patent search was conducted, and the following numbered United States patents related to sheet stiffening processes were reviewed: 331,469; 662,567; 1,158,667; 1,685,320; 1,984,653; 2,020,639; 2,129,488; 2,310,154; 2,423,870; and 2,481,046. United States Patent No. 2,738,297, dated 13 March 1956, covering the CALOTTAN process was included in the review. Switzerland Patent No. 73,542 and German Patent No. P7282 v/37b cover the CALOTTAN process in those countries.

A literature search and study confirmed information that the University of North Carolina was making studies of rigidized

metallic sheet. However, the work at that institution was concerned with the use of reinforcing ribbing and special shaped panels. An article by Adam Zahorski, "Effects of Material Distribution on Strength of Panels," Journal of the Aeronautical Sciences, July 1944, and an article by K. Lowenfeld, "15 Plate-stiffenings," the digest of a two-part German article, "Product Engineering," Vol. 29, No. 29, 21 July 1958, were of special interest.

The study revealed that two companies operating in the United States engage primarily in producing metal sheet stiffened by patterns of depressions and elevations formed in the metal; also, four companies operating in the United States produce sheet having decorative surface patterns.[1] The authors are familiar also with sandwich constructions and core materials and the standard military procedures used to evaluate them, as outlined in MIL-STD-401A.

The most attractive claims revealed by the study for true rigidized sheet approaching equal stiffness in all directions parallel to the plane of the sheet, were made for the CALOTTAN process, U. S. Patent No. 2,738,297. The developers claimed that the rigidity of calottized steel sheet is 10 times that of plain steel sheet and that a two-ply combination of calottized sheet will support twenty-five times the load supported by a single calottized sheet. Also, they claimed that calottized sheet is fully curved in every principal direction of stress, has "no preferred axes of inertia," and has "rigidity many times greater than that of any known material of this type."

The claims made by other producers for the effects of their stiffening patterns justified including data for only one other pattern in this report for comparison with calottized sheet. This pattern is referred to throughout this report as the "X" Company pattern. The data for sheet rigidized by this pattern were taken from a bulletin published by X Company.

4. Study of CALOTTAN Stiffening Pattern Design. The CALOTTAN patent appears to cover sheet rigidized by molding or forming into depressions and elevations of various shapes. This investigation was limited to the formed pattern which we understand is preferred by the developers of the process (Figs. 1 and 2).

a. Description. The surface of a flat sheet material is deformed into closely adjacent depressions and elevations called calottes (Figs. 1 and 2). The height of the calottes can be varied

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1. See the insert sheet for the names of the companies producing rigidized sheet and sheet with decorative surface patterns.

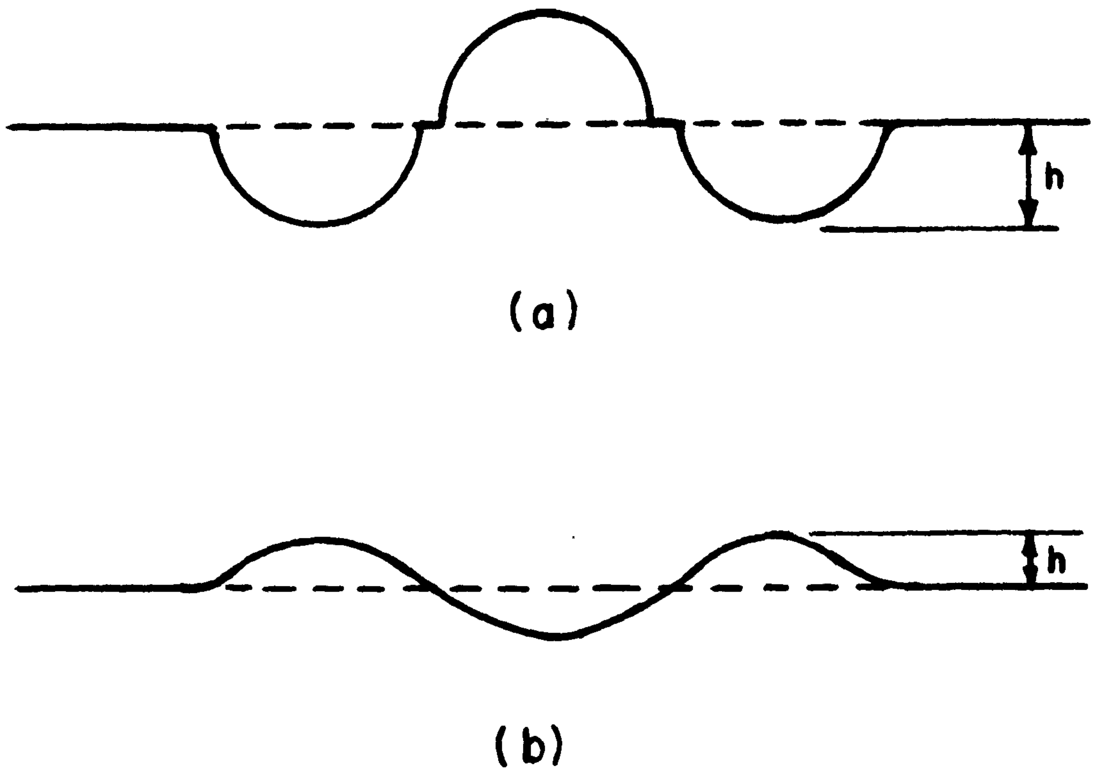

Fig. 2. Edge of sections through calottes. (a) Maximum calottes. (b) Optimum calottes.

by regulating the travel of the mating forming dies which controls the distance the male plungers force the sheet into registering female receptacles. This allows the press operator to vary the calottes from small segments of hollow spheres to complete hollow hemispheres. However, the travel of the plungers at full closure of the particular forming dies loaned by the developers for use in this investigation was not enough to form complete hollow hemispheres. The developers claim that this preferred pattern provides formed sheet fully curved in every principal direction of stress.

b. Approach. To evaluate and use the laboratory test data efficiently an understanding of the CALOTTAN pattern design is imperative. It was found that the pattern can be resolved into five basic parts:

(1) The calotte (Fig. 2).

(2) The CALOTTAN key unit (Fig. 3, at the center).

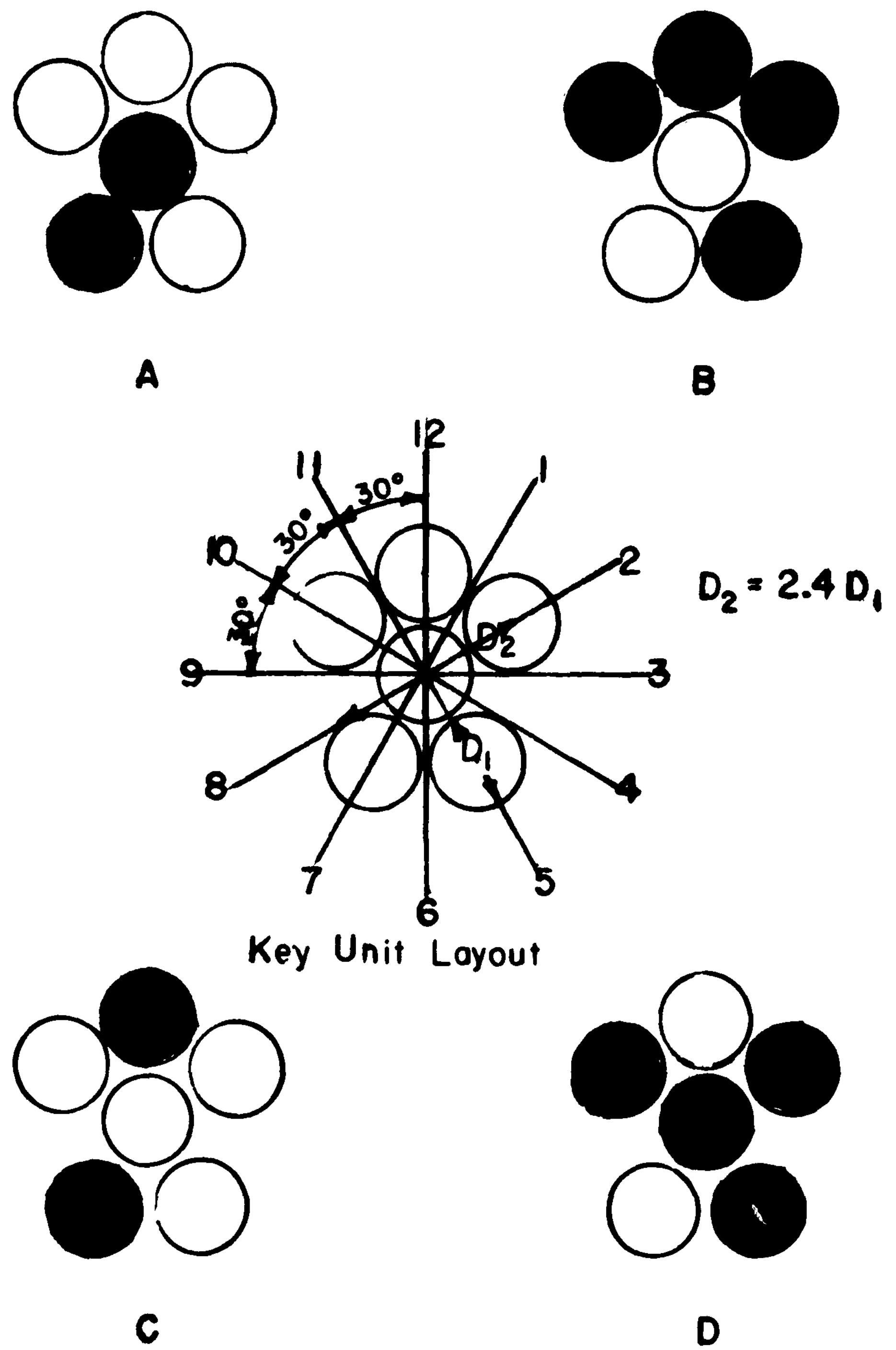

Fig. 3. CALOTTAN key unit.
Note: Shaded calottes are concave; unshaded are convex.
(This description applies to Figs. 4 through 6.)

(3) The CALOTTAN skeleton half module pattern (Fig. 4).

(4) The CALOTTAN skeleton module pattern (Fig. 5).

(5) The CALOTTAN module pattern (Fig. 6).

The calotte height (or depth) h in Fig. 2 is also of prime importance in a study of the pattern. A section of the forming die (Fig. 7) illustrates how the calottes are formed.

c. Key Unit. The layout for the base or key unit of the CALOTTAN design is shown at the center of Fig. 3. It is formed upon a circle divided into 12 equal sectors as the face of a clock. Location of the six calottes is represented by the small circles. As calottes are formed either concave or convex the four variations of the key required to complete the CALOTTAN pattern are shown in the figure and are identified as A, B, C, and D. Key A has a concave calotte at the center and at the 7 o'clock position on its circumference and convex calottes at the 10, 12, 2, and 5 o'clock positions. Key variation B has a convex calotte at the center and 7 o'clock position and concave calottes at the 10, 12, 2, and 5 o'clock positions.

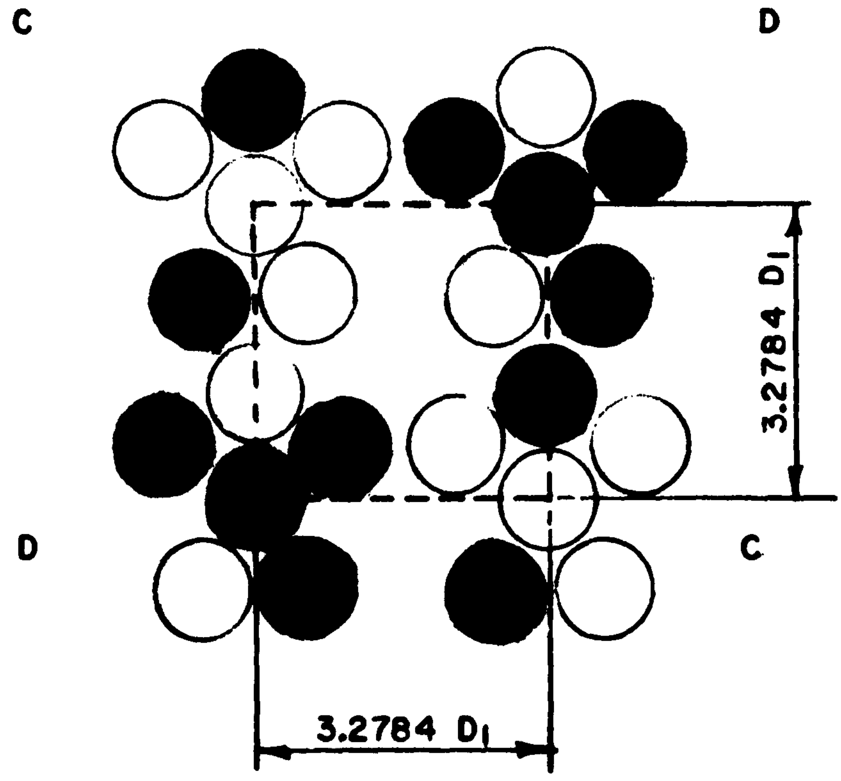

Fig. 4. CALOTTAN half module pattern.

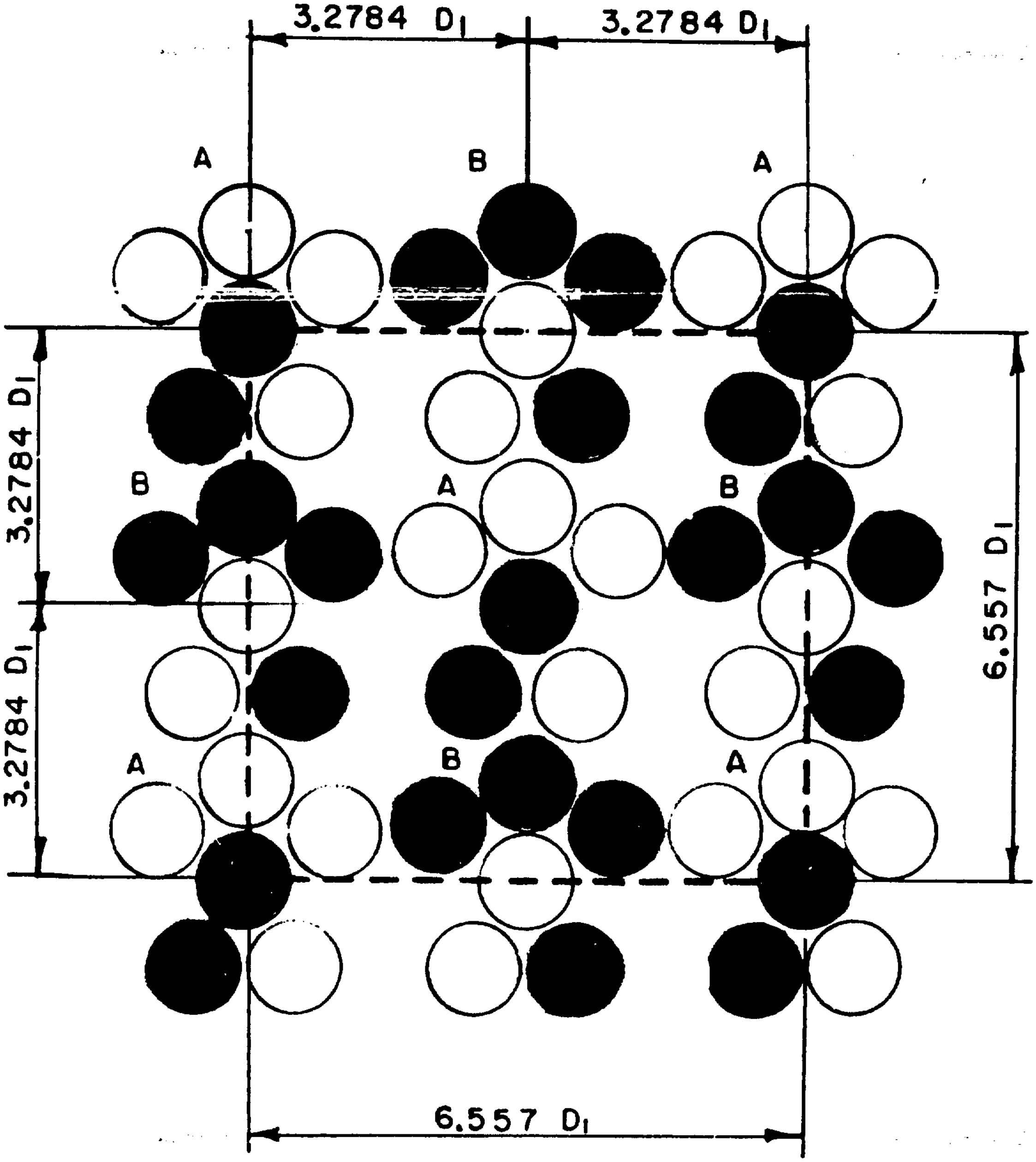

Fig. 5. CALOTTAN skeleton module pattern.

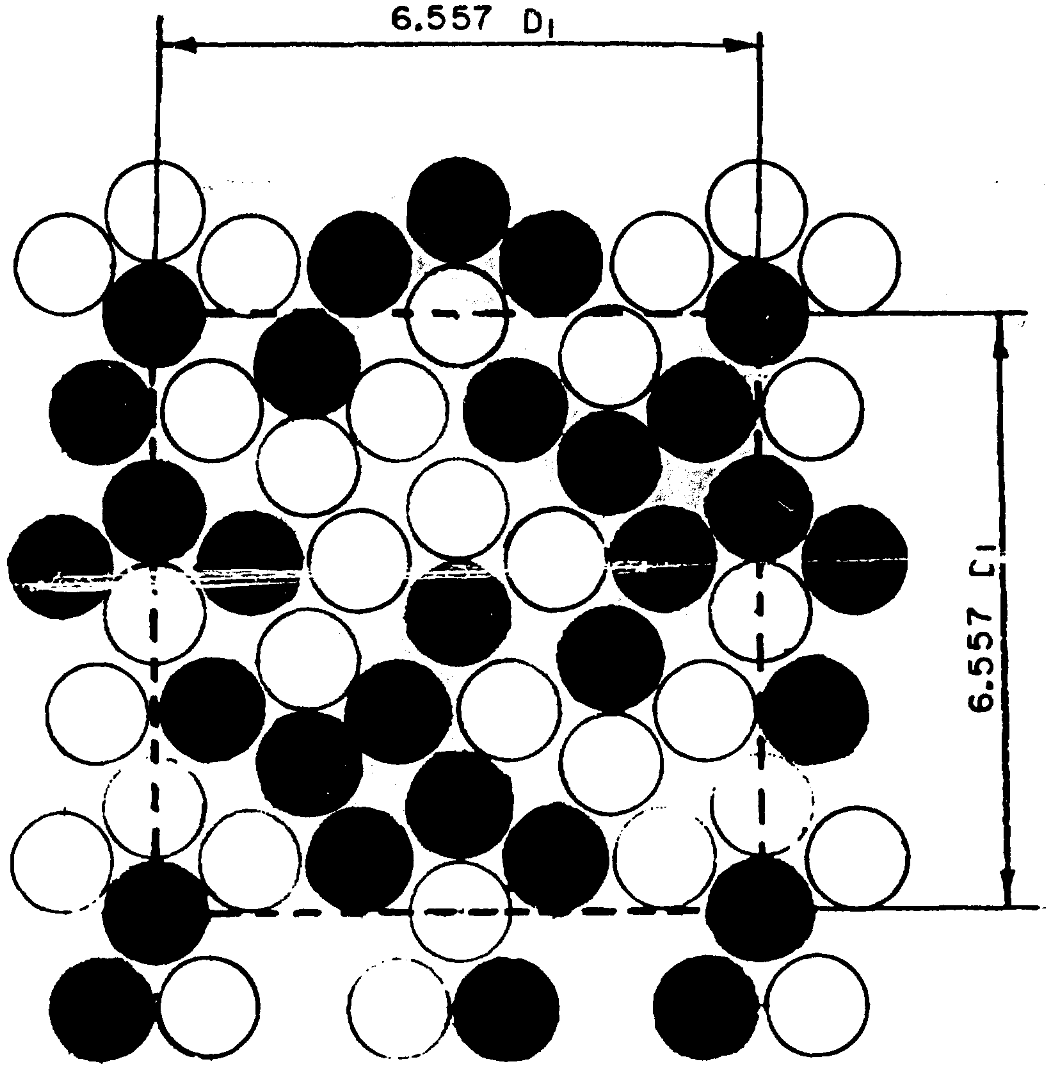

Fig. 6. CALOTTAN module pattern.

Variation C has a convex calotte at the center and at the 10, 2, and 5 o'clock positions and concave calottes at the 7 and 12 o'clock positions. Variation D has a concave calotte at the center and at the 10, 2, and 5 o'clock positions and convex calottes at the 7 and 12 o'clock positions. Note that the positions of the convex and concave calottes in the A and C variations of the key are reversed in the B and D variations, respectively. The diameter of the key unit layout circle is based on the maximum inside diameter of the calottes (maximum diameter of the forming plunger of the die). The maximum diameter of the calotte-forming plunger of the die used in this investigation was 20 mm or 0.7874 inch (Table I and Fig. 7). To

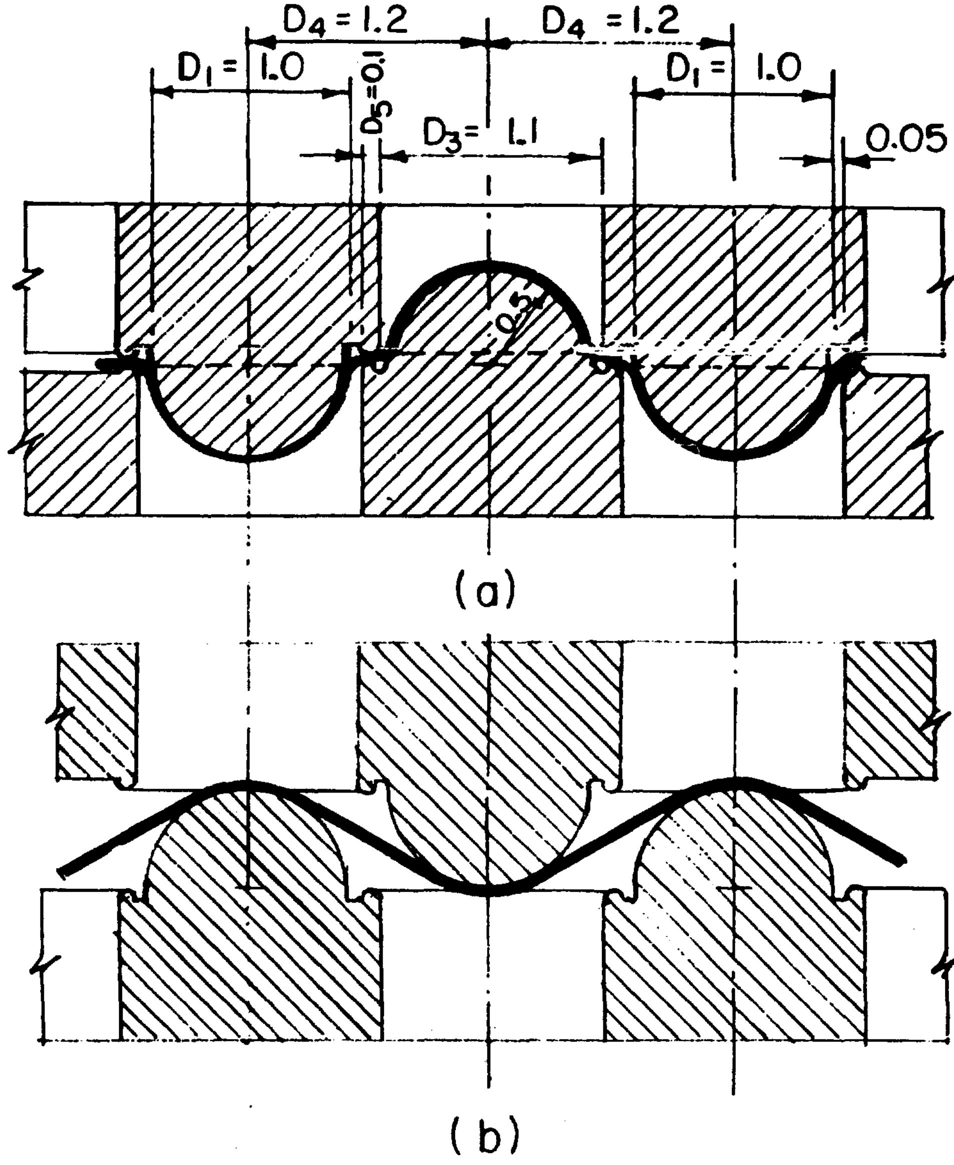

Fig. 7. Sections of forming die showing how calottes are formed. (a) Forming maximum calotte height. (b) Forming optimum calotte height (die partly closed).

simplify analysis and discussion of the stiffening design, the maximum diameter D_1 of the calotte-forming plunger is taken as unity. The proportional measurements of the basic parts of the stiffening design then become:

D_1	Maximum diameter of plunger	1
D_2	Diameter of key unit circle	2.4
S_1	Side of half module square	3.2784
S_2	Side of module square	6.557

d. Skeleton Half Module Pattern. The CALOTTAN skeleton half module pattern is shown in Fig. 4. It consists of four key units, two C and two D, with their centers at the corners of a square 3.2784 D_1 on a side. Diagonally adjacent units are alike, but in immediate adjacent units positions of the concave and convex calottes are reversed.

e. Skeleton Module Pattern. The CALOTTAN skeleton module pattern is shown in Fig. 5. It consists of nine key units, five A and four B. The centers of four A units are at the corners of a square 6.557 D_1 on a side, and the fifth A unit is at the center of the square. The center of a B unit is at the half point of each side of the square. As in the half module pattern, diagonally adjacent units are alike, but in immediate adjacent units positions of the concave and convex calottes are reversed.

f. CALOTTAN Module Pattern. The complete CALOTTAN module pattern is shown in Fig. 6. It is formed by superimposing the skeleton half module pattern (Fig. 4) on the center of the skeleton full module pattern (Fig. 5) with the sides of the two squares parallel. A sheet is calottized by forming it in a pattern which repeats, as required by the area of the sheet, that part of the CALOTTAN module pattern within the 6.557 D_1 square. For dies of the type used in this investigation the module length is always proportional to the maximum inside diameter of the calotte (D_1), so modules of the length needed to meet a specific design requirement may be produced by adjusting the calotte diameter and designing the forming dies to the proportions given in paragraph 4c and Table I of this report. Obviously, if economically desirable, more than one module unit can be incorporated in a single set of forming dies. Information supplied by the developers indicates punches with smaller heads were sometimes used in the dies shown in Table I to adapt them for forming thicker sheet.

Table I. CALOTTAN Die Dimensions

Symbol	D_1		D_3		D_4		D_5			
Part	Maximum Punch Diam.		Hole Diam.		Center to Center of Holes		Land Width		Sheet Thickness	
Units	(mm)	(in.)	(mm)	(in.)	(mm)	(in.)	(mm)	(in.)	(mm)	(in.)
Dimensions	10	0.394	11	0.433	12	0.472	1	0.039	0.0-1.0	0.0-0.039
	20	0.787	22	0.866	24	0.945	2	0.079	0.5-1.5	0.020-0.059
	30	1.181	33	1.299	36	1.417	3	0.118	1.0-2.0	0.039-0.079
	40	1.575	48	1.732	48	1.890	4	0.157	2.0-3.0	0.079-0.118
Relative Size	1.0	(Unity)	1.1		1.2		0.1			

Note: Dimensions of the die used for this investigation are shown in the second line of dimensions.

g. Increase in Surface Area. Although the size of sheet remains the same, its surface area and its thickness (in the sense of space required) is increased by calottizing. The surface area of a sheet that is 100 percent calottized (having calottes that are complete hollow hemispheres) is increased about 58 percent, but a 50 percent calottized sheet has its surface area increased only 10 percent (Fig. 8). The thickness of an 0.018-inch sheet is increased to about 3/4 inch by 100 percent calottizing in the sense that the deformed sheet will separate two planes by that amount. This increase can be alleviated for shipping by nesting bulk calottized sheet in bundles but it must be considered in designs utilizing the rigidized sheet.

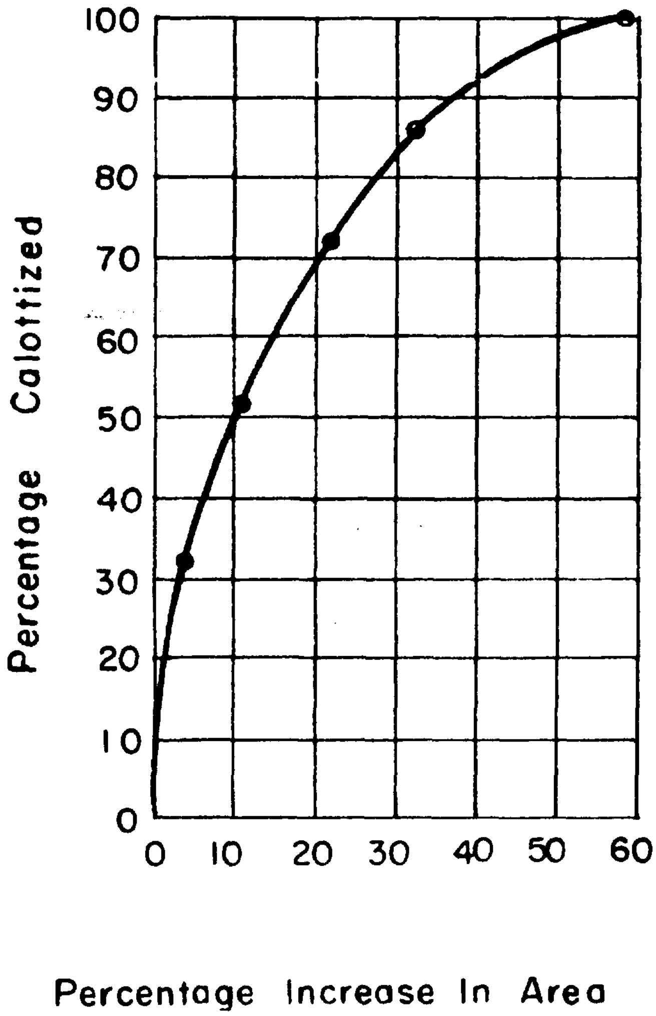

Fig. 8. Increased surface area of calottized sheet.

5. Nesting, Interlocking, and Laminating Calottized Sheet. It was shown in pars. 4d, e, and f that half and full skeleton module patterns are superimposed one upon the other to form the complete CALOTTAN stiffening pattern and that this square pattern 6.557 D_1 on a side is repeated as required to calottize a sheet. As each calottized sheet with the same calotte diameter D_1 is made up of a series of these squares in which the calotte forms and locations are identical, two or more such sheets will nest if stacked so the pattern squares register. This nesting feature can also be utilized for interlocking and joining calottized sheet, by nesting the overlapped edges of adjacent sheet so they interlock as illustrated by Fig. 9. A further advantage of the repeating pattern is that calottized sheet can be placed in layers so the top of each convex calotte of the lower sheet contacts the bottom of each concave calotte of the superimposed sheet to produce a laminated-type structure as shown in Fig. 10. This can also be done with calottized sheet having different calotte diameters (D_1) if the calotte diameter in one sheet is a multiple of that of the others (Fig. 11). It is stressed by the developers of the CALOTTAN process that the spaces between laminated calottized sheet can be filled with various materials or combinations of materials to provide heat resistance, hardness, or to further increase the stiffness of the composite structure as desired for special applications. It is obvious from Figs. 10 and 11 that filler materials can be used but none were tried in this investigation.

III. TESTS

6. Preparation of Test Specimens. Materials used and the fabrication of test specimens are considered in the following subparagraphs.

a. Materials. Commercial quality steel and aluminum sheet was used for all forming, deflection, and impact test specimens. Details concerning the materials used and considered as a result of tests by others are included in Table II. Exploratory single sheet of galvanized steel and of copper, magnesium, and titanium were tested for formability by calottizing but were not included in the other tests.

b. Fabrication of Test Specimens. A 300,000-lb capacity Baldwin-Tate-Emery testing machine was used as a press to produce the calottized sheet for test specimens. The first sheet calottized was formed in dies cast in our shops. The dies were made by using a sample calottized sheet supplied by the representatives of the CALOTTAN process as a form for the mold. The cast dies proved

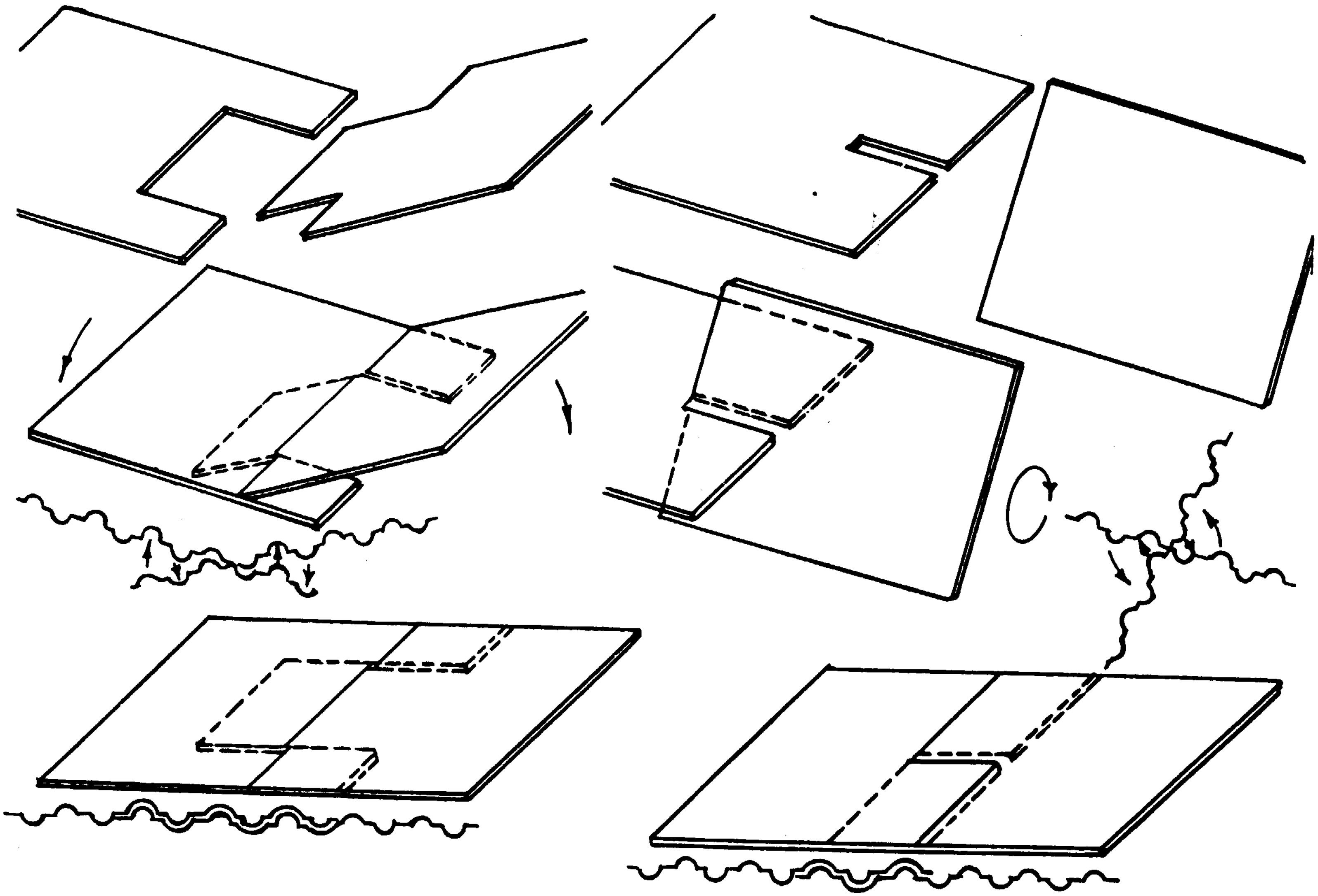

Fig. 9. Joining calottized sheet by interlocking edge calottes.

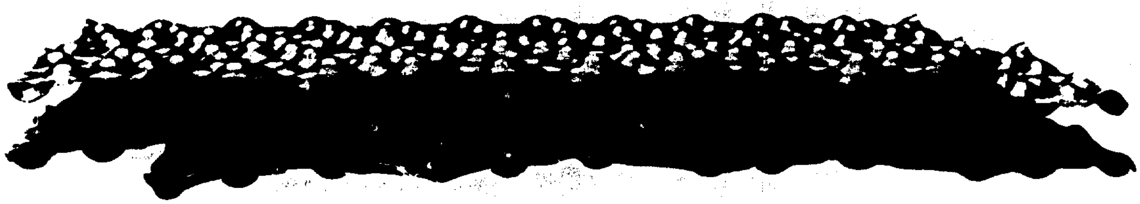

Fig. 10. Laminated structure of calottized sheet.

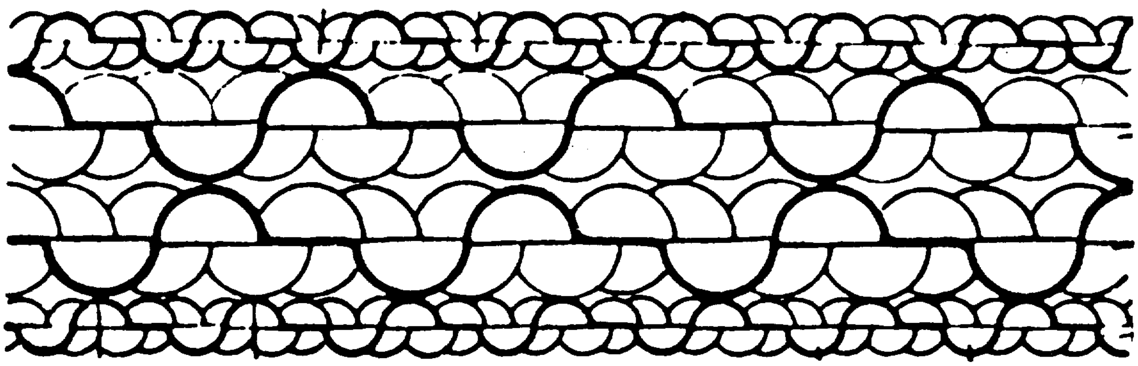

Fig. 11. Laminated structure of calottized sheet with different calotte diameters.

Table II. Materials Considered in CALOTTAN Investigation

Material	Type	Thickness (in.)	Hardness (DPH)	Hardness (BHN*)	Fig.	Remarks
Mild Steel	0.05 Carbon	0.018	87		13	
"	0.05 "	0.018	87		21	Two-layer specimens.
"	0.05 "	0.035	87		14	
"	0.05 "	0.059	87		15	Two-layer specimens.
Aluminum	1100-0	0.014		17.5	17	
"	1100-H16	0.015		39.0	18	
"	1100-H12	0.035			21	Two-layer specimens.
"	1100-H12	0.035		26.5	16	
"	5052	0.037			16	
CRC Steel	1010	0.018			23	Sheet rigidized by "X" Company.
"	1010	0.060			23	" " " " "
Aluminum	3003-0	0.035			23	" " " " "
Plastic	Vinylite	0.017			-	Materials Branch Report No. 6126-3.

* Ten-mm steel ball, 500-kg load.

unsatisfactory and were discarded. A release agreement (No. 1028) was then made with the CALOTTAN representatives covering the loan to these Laboratories of their original steel plunger-type forming dies, and these were used to calottize the sheet for test specimens. The dies calottized a rectangular area 9.3 by 17.75 inches in size with one stroke of the press. They formed calottes having a maximum inside diameter D_1 of 20 mm or 0.7874 inch and a maximum height of 9 mm or 0.354 inch. Sheet was cut to a size permitting calottizing the whole sheet with one stroke. Each sheet was wiped with a cloth to remove surface contaminates that might produce blemishes, but no lubricants were used. All sheet was formed at press room temperature which was maintained at 73° F. The relative humidity of the room was 50 percent. A die closure rate of less than 1 inch per minute was used. The height of calottes produced by various pressures was determined for each material and thickness of sheet and is shown in Fig. 12 for 0.035-inch mild steel. Control of the calotte height by applying the correct predetermined pressure gave more reproducible results on the testing machine "press" than attempts to control the calotte height by controlling the die closure clearance. This will not necessarily be true with some production presses.

Sheet was prepared with calottes of various heights so the optimum height for maximum rigidity could be determined. No 100 percent calottized sheet could be made; 80 percent was the maximum possible with the dies furnished. Also, difficulty was experienced in producing sheet calottized much above the optimum without material failure by cracking at the base of the hollow spherical segment, that is, the top of a calotte and sometimes across the top of the calotte. This was not an important problem in our investigation because the optimum height of the calotte was found to be within our forming capabilities. However, when one considers calottized sheet for heat exchangers, and for filled laminated structures requiring hemispherical calottes, it is important to realize that the neat appearing 80 to 100 percent calottized sheet which are normally shown in the CALOTTAN literature and are represented by the figures in the CALOTTAN patent cannot be produced by cold forming from most of the materials tried in this investigation. Hot forming or very ductile materials are required.

To prepare the specimens for deflection tests, a centerline was established parallel to the sides of the pattern squares on calottized sheet of appropriate size. Specimens 8.46 inches (215 mm) by 17.75 inches were cut on the centerline and at angles to the centerline of 15°, 30°, 45°, 60°, 75°, and 90°. Multilayer specimens were made by bolting two specimens together of like size and calotte height but positioned a half module out of register so the calottes contacted as shown in Fig. 10. Four bolts

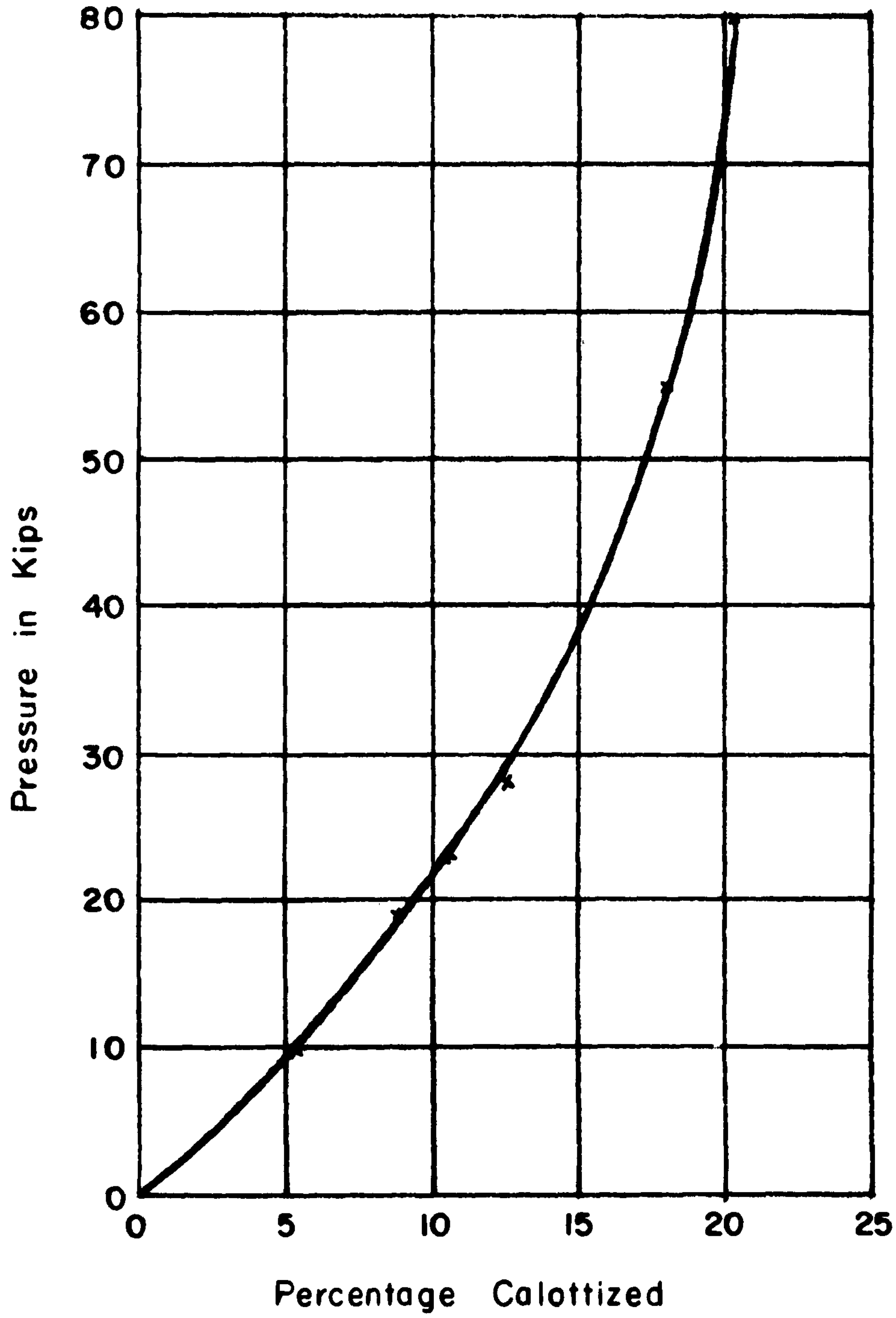

Fig. 12. Pressure required to cold form 165-square inch area of 0.035-inch mild steel sheet with 0.787-inch I. D. calottes.

were used, one located at each longitudinal and transverse third point. The multilayer or two-ply laminates were made from sheet calottized with approximately the optimum height calottes for single sheet.

7. Test Equipment. A 60,000-lb-maximum capacity Southwork Baldwin-Tate-Emery testing machine with an A. H. Emery Company air cell adapter to convert the 0- to 600-lb range to 0- to 60-lb range was used for the deflection tests. An electrically operated micro-former recorder connected to a PD-1M deflectometer was used to plot deflection versus applied load. The recorder was adjustable for a number of testing ranges. Loads too small for the testing machine were applied by loading the specimens with metal granules.

The impact test and the equipment used for the test were improvised for this investigation. The equipment consisted of an 8-inch I. D. steel cylinder placed on end on a concrete floor. The cylinder was used to support the sheet under test. There was an arrangement for dropping a 2.25-inch-diameter steel ball weighing 897 grams a measured distance to strike the sheet at the center of the area supported by the steel cylinder.

An electromagnetic vibration exciter was used for the vibration testing.

8. Deflection Tests. Deflection measurements were made on samples from calottized sheets prepared as described in par. 6b. The 8.46-inch (215 mm)-wide samples were supported as simple beams with a span of 16.02 inches (407 mm) and were loaded on the transverse centerline. The 20-mm by 407-mm dimensions were selected to correspond to those used in some tests reported by the representatives of the CALOTTAN process.

a. Tests of Single Calottized Sheet. Including preliminary and exploratory work, about 250 deflection tests were made of single calottized sheet of the various materials and thicknesses shown in Table II. The results of the tests are shown by the curves (Figs. 13 through 18) and the graph (Fig. 19). The results shown in Figs. 13 through 18 are from specimens cut parallel to the longitudinal centerline of the calottized sheet. Those shown by Fig. 19 are from specimens cut at angles to the centerline and tested to determine if the CALOTTAN pattern provides uniform rigidity throughout the sheet. Figure 20 compares the loads carried by plain and calottized sheet.

A deflection of 1 inch was selected after exploratory tests as adequate to give the information desired without stressing

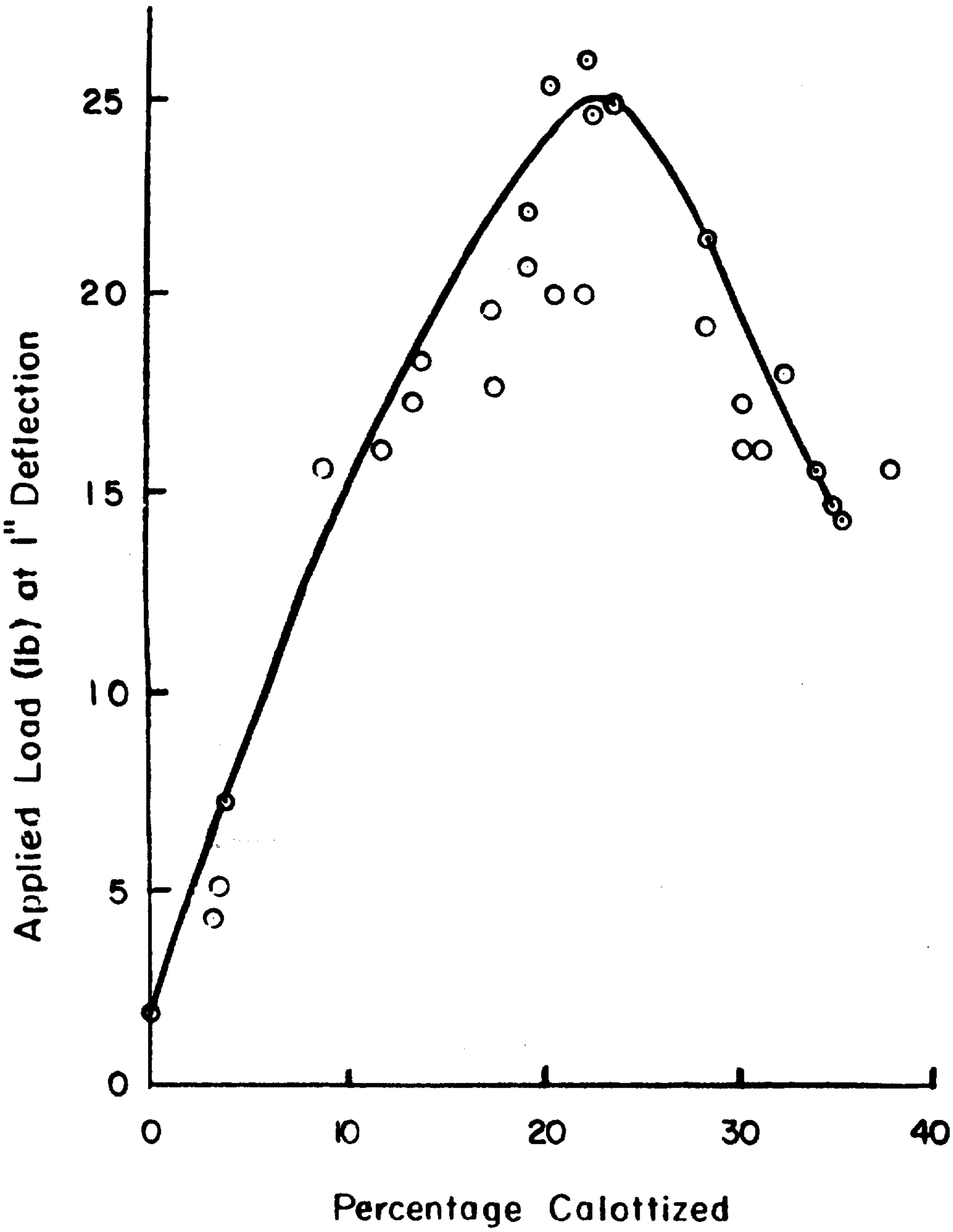

Fig. 13. Load vs percentage of calottized 0.018-inch mild steel sheet.

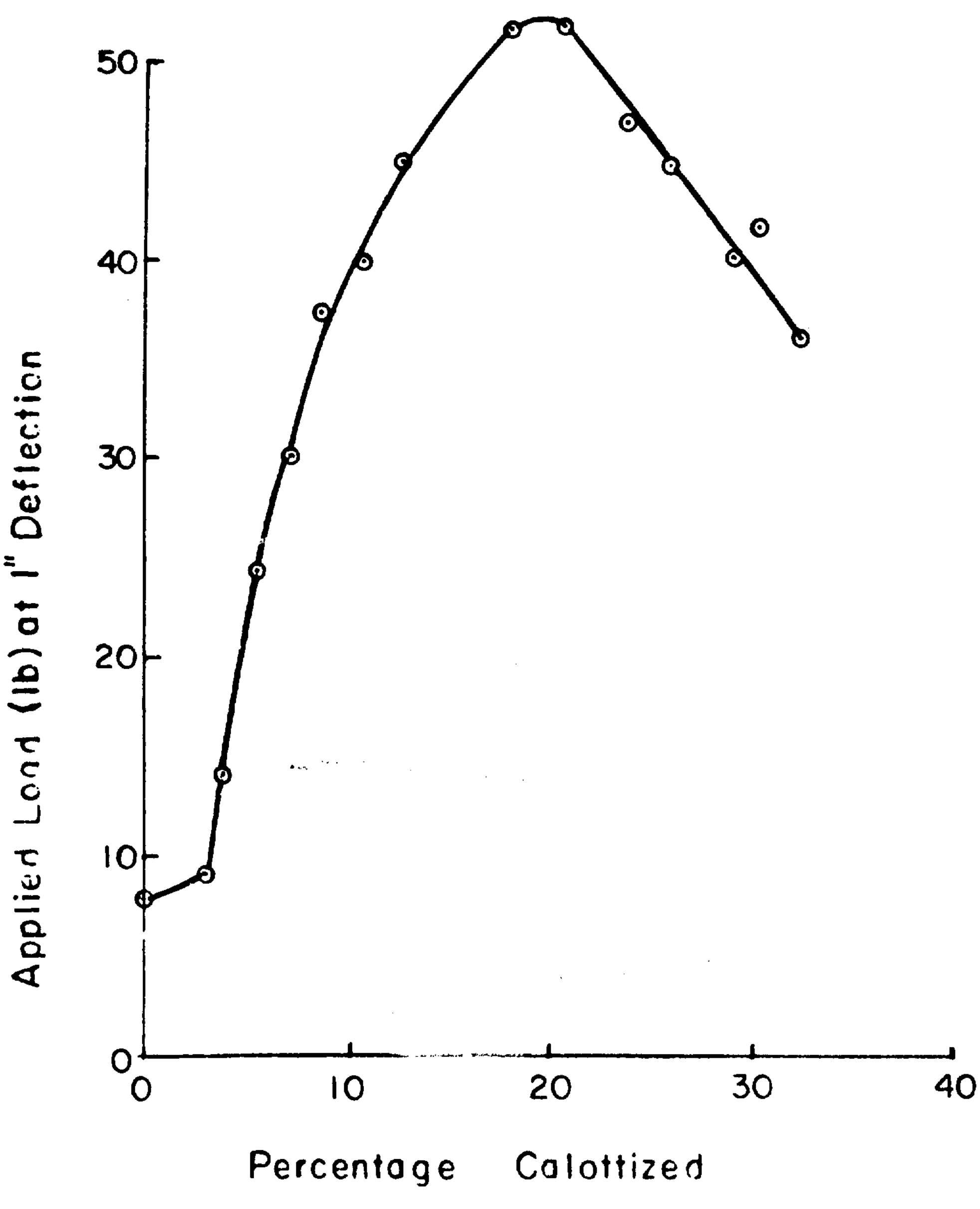

Fig. 14. Load vs percentage of calottized, 0.035-inch mild steel sheet.

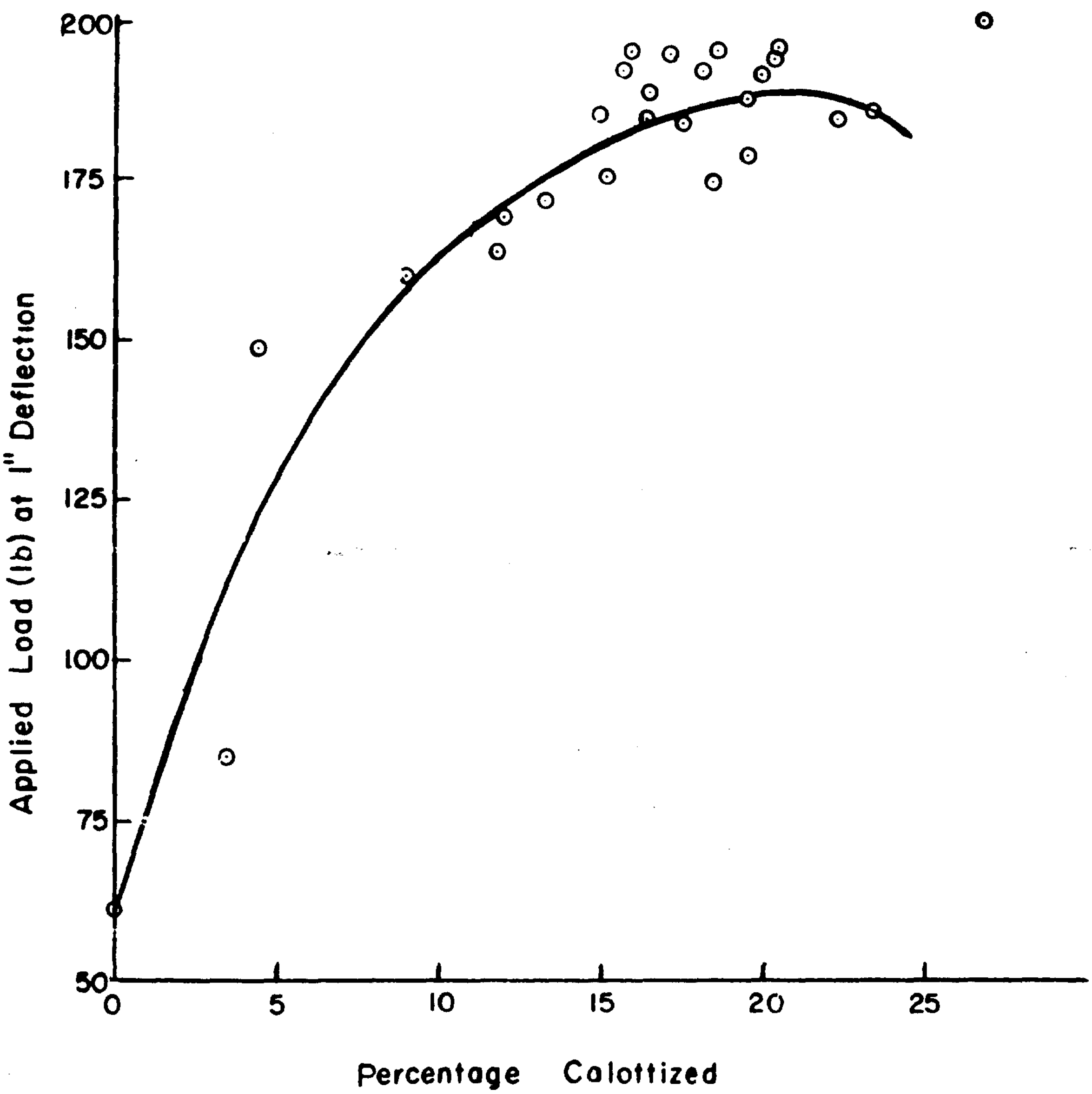

Fig. 15. Load vs percentage of calottized, 0.059-inch mild steel sheet.

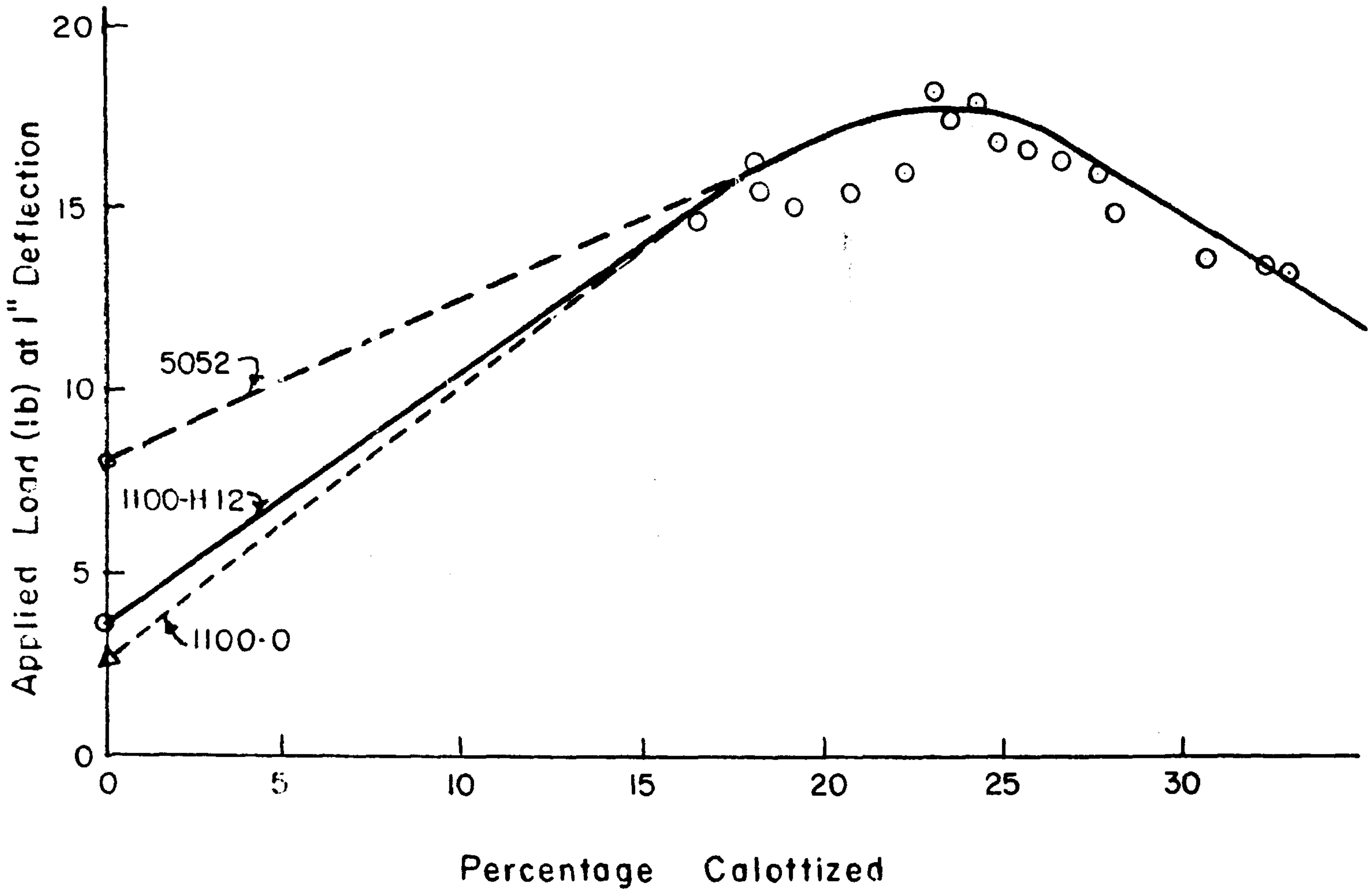

Fig. 16. Load vs percentage of calottized, 0.035-inch, 1100-H12 and 5052 aluminum-alloy sheet.

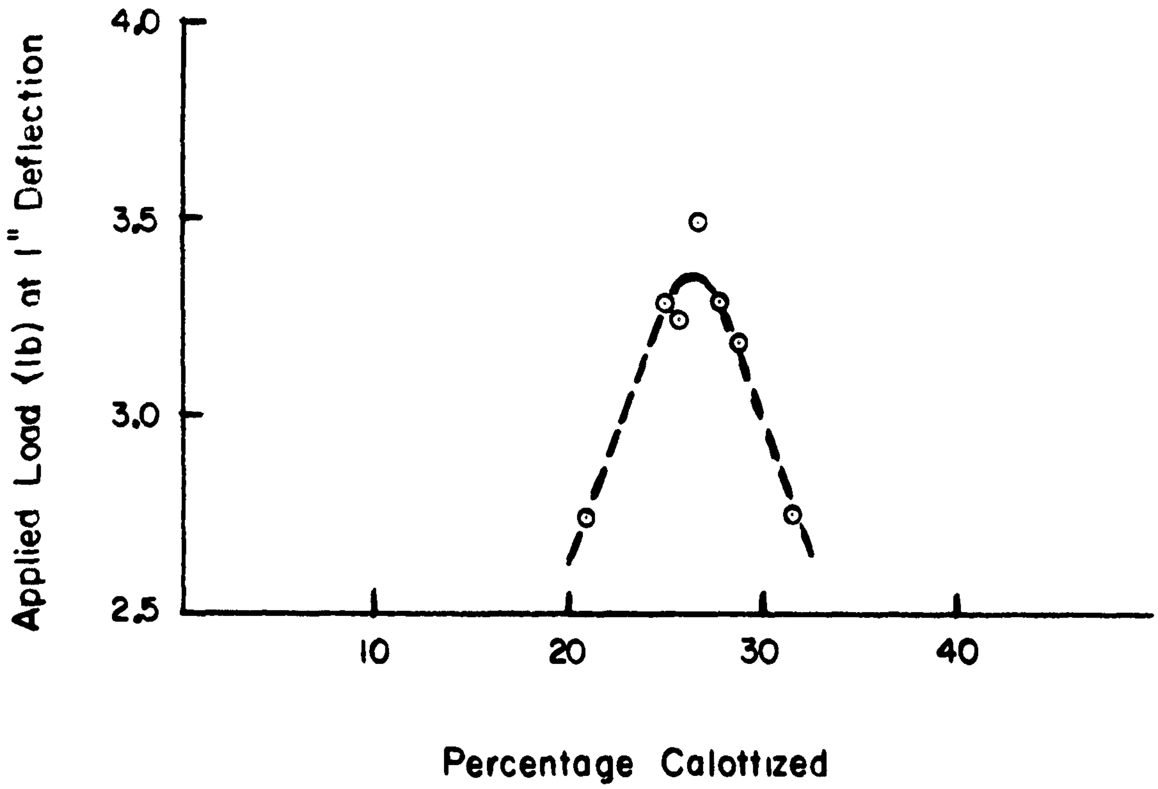

Fig. 17. Load vs percentage of calottized, 0.014-inch, 1100-0 aluminum-alloy sheet.

the materials beyond their yield points. Therefore, the load reported is always the applied load required to produce a deflection of 1 inch at the center of the span of the simple beams.

b. Tests of Multilayer Calottized Sheet. A number of deflection tests were also made on two-ply laminates of calottized sheet. Typical results of these tests are shown in Fig. 21. The results are compared directly with those from the tests of single sheet as the applied loads reported are always at 1-inch deflection.

c. Deflection Data for X Company Rigidized Sheet. The data for the X Company rigidized sheet which are compared in this report with similar data for calottized sheet were obtained from a complete report of tests of materials furnished by the Company. The data used are for their stiffening pattern which gave the best EI values and is somewhat similar in appearance to the CALOTTAN pattern. In considering these data, note that the X Company test specimens were prepared from the plain unprocessed portion of the sheet and

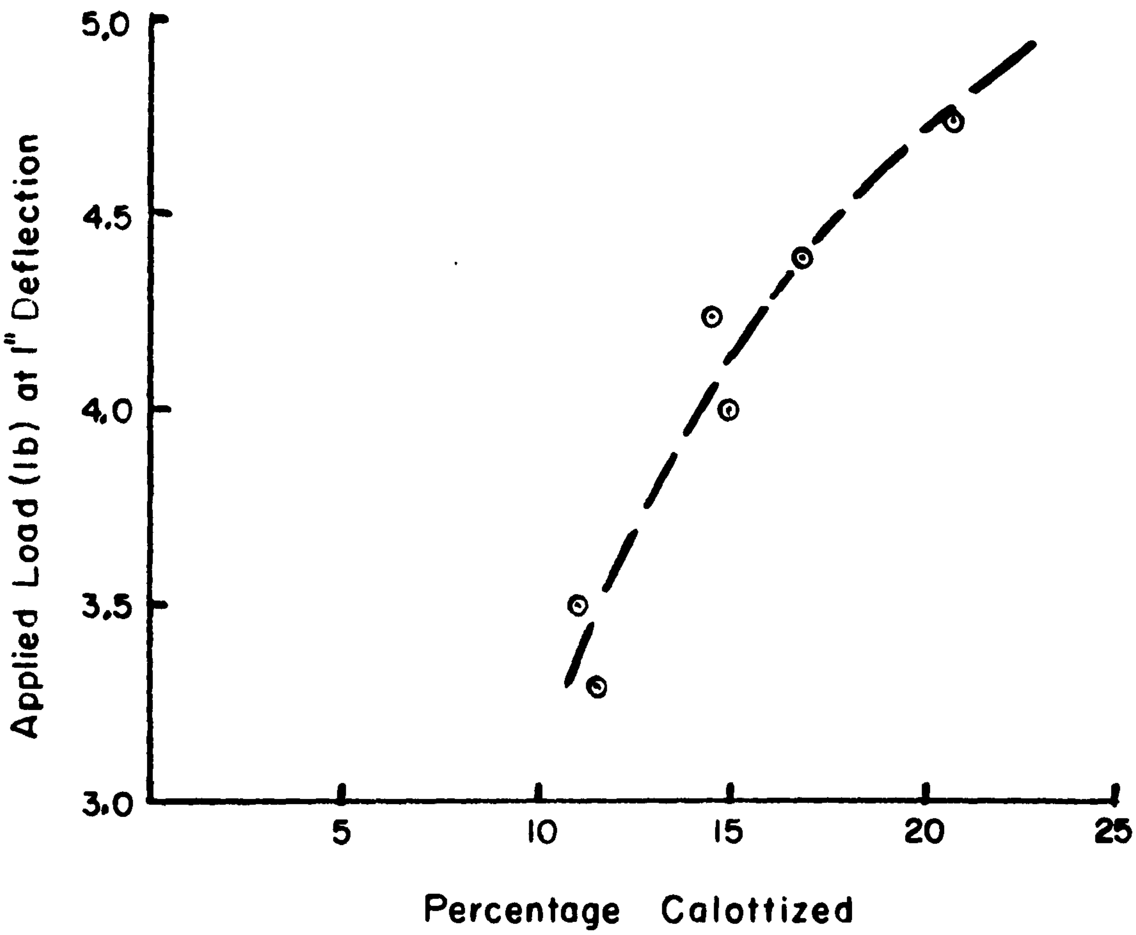

Fig. 18. Load vs percentage of calottized, 0.015-inch, 1100-H16 aluminum-alloy sheet.

from a rigidized portion of the same sheet. The rigidized specimens were oriented so the primary lines of the pattern approximately paralleled the longitudinal and transverse centerlines of the specimen.

9. Impact Tests. Mild steel and aluminum-alloy sheet both plain and calottized by cold forming were tested for resistance to impact with the improvised equipment described in par. 7. The amount of permanent deflection of the sheet caused by an impact force of 3.92 ft-lb was recorded. Sheet calottized with calottes of various heights was included. Results of the tests of 0.018-inch steel sheet and 0.035-inch aluminum sheet are shown by the curves in Fig. 22.

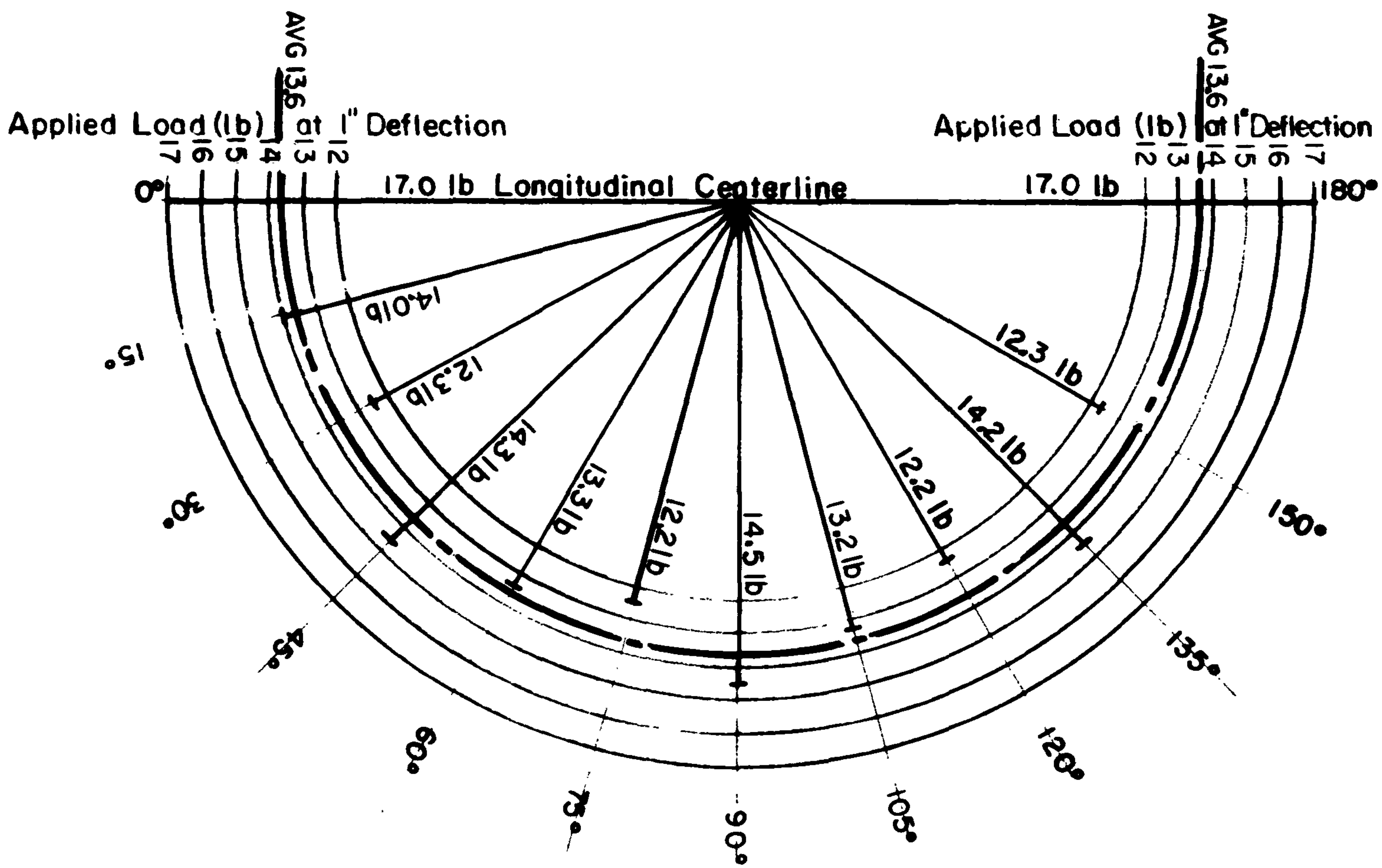

Fig. 19. Directional rigidity of calottized sheet (0.035-inch aluminum sheet, 23.5 percent calottized).

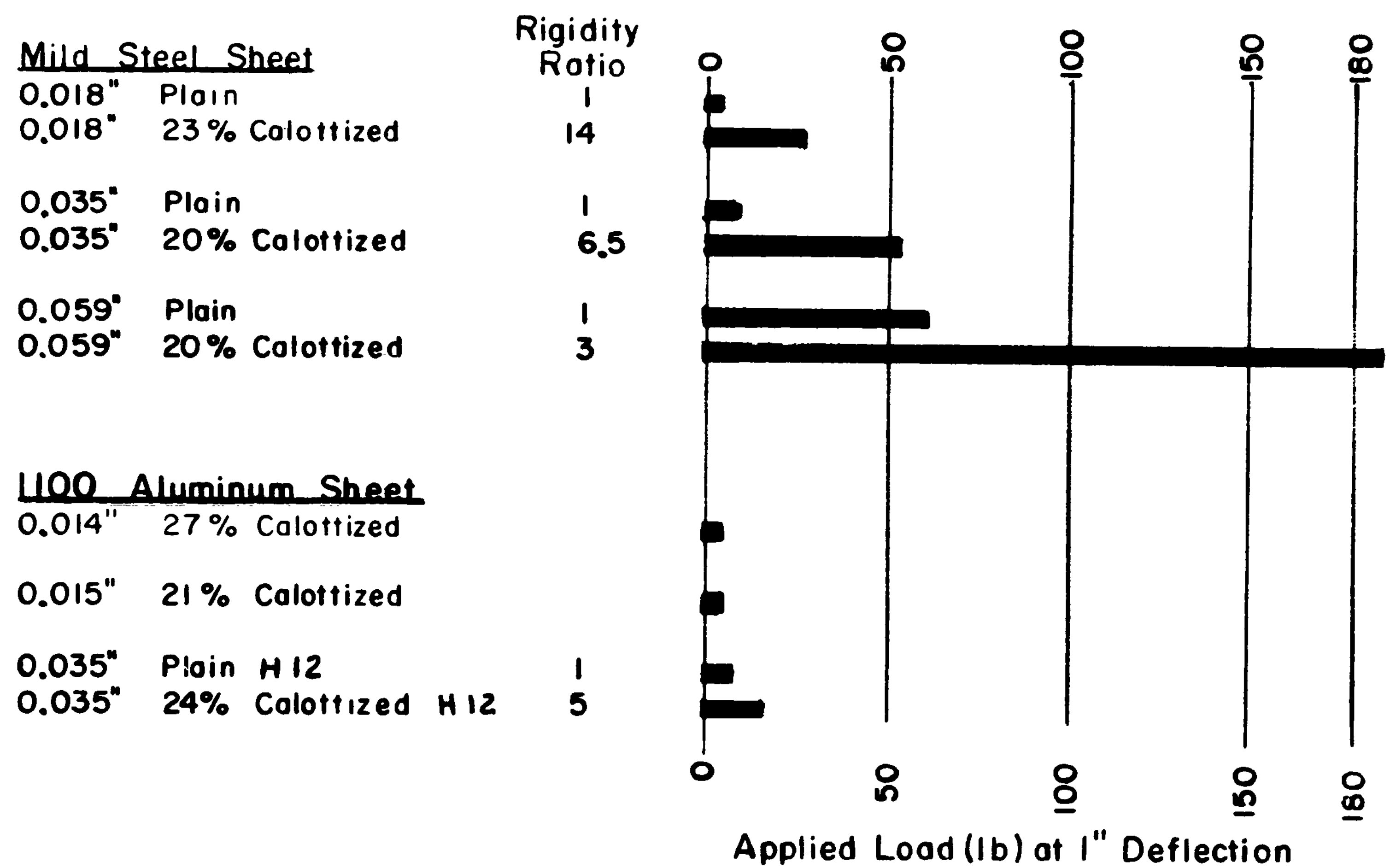

Fig. 20. Comparison of typical loads carried by plain and calottized sheet.

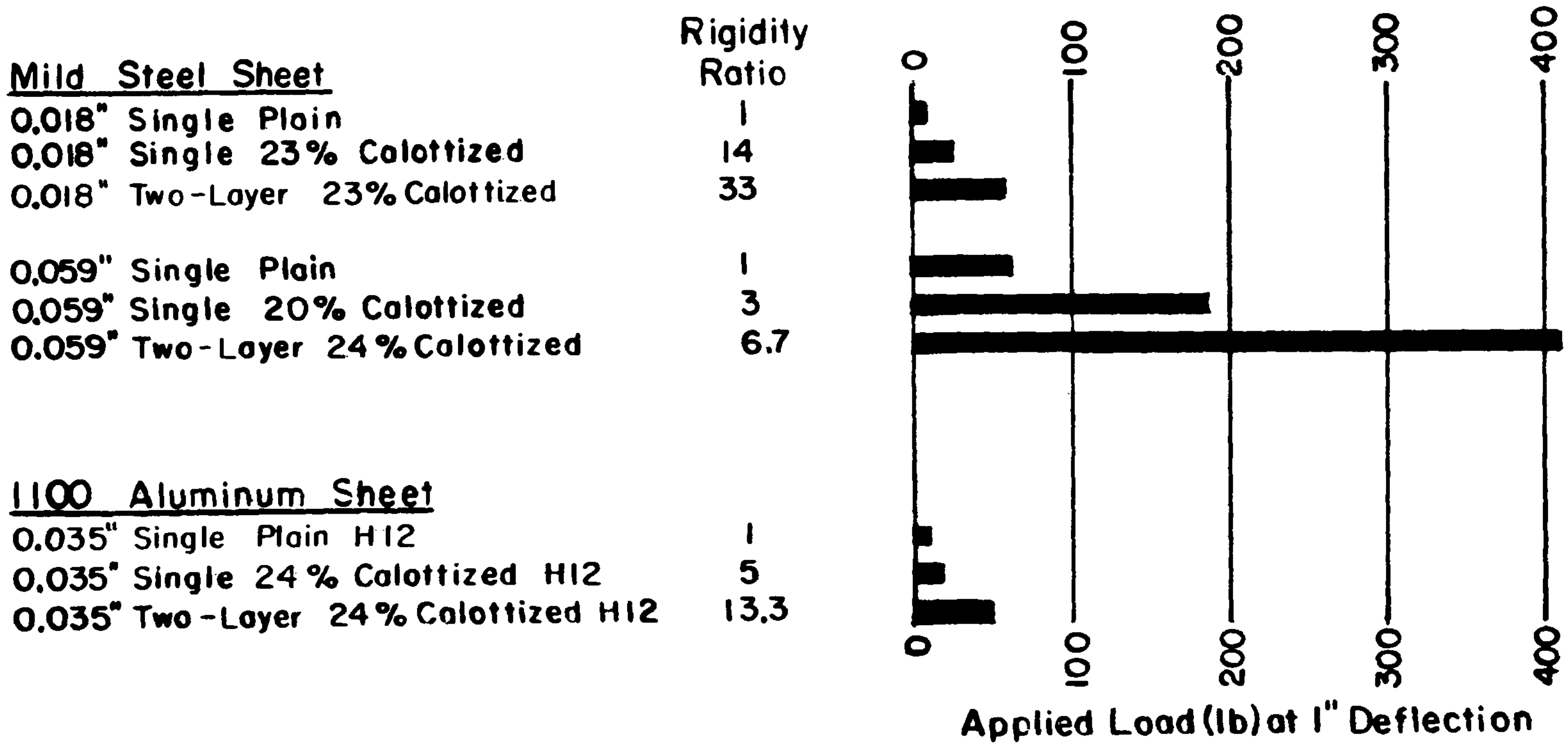

Fig. 21. Comparison of typical loads carried by plain, single, and two-layer calottized sheet.

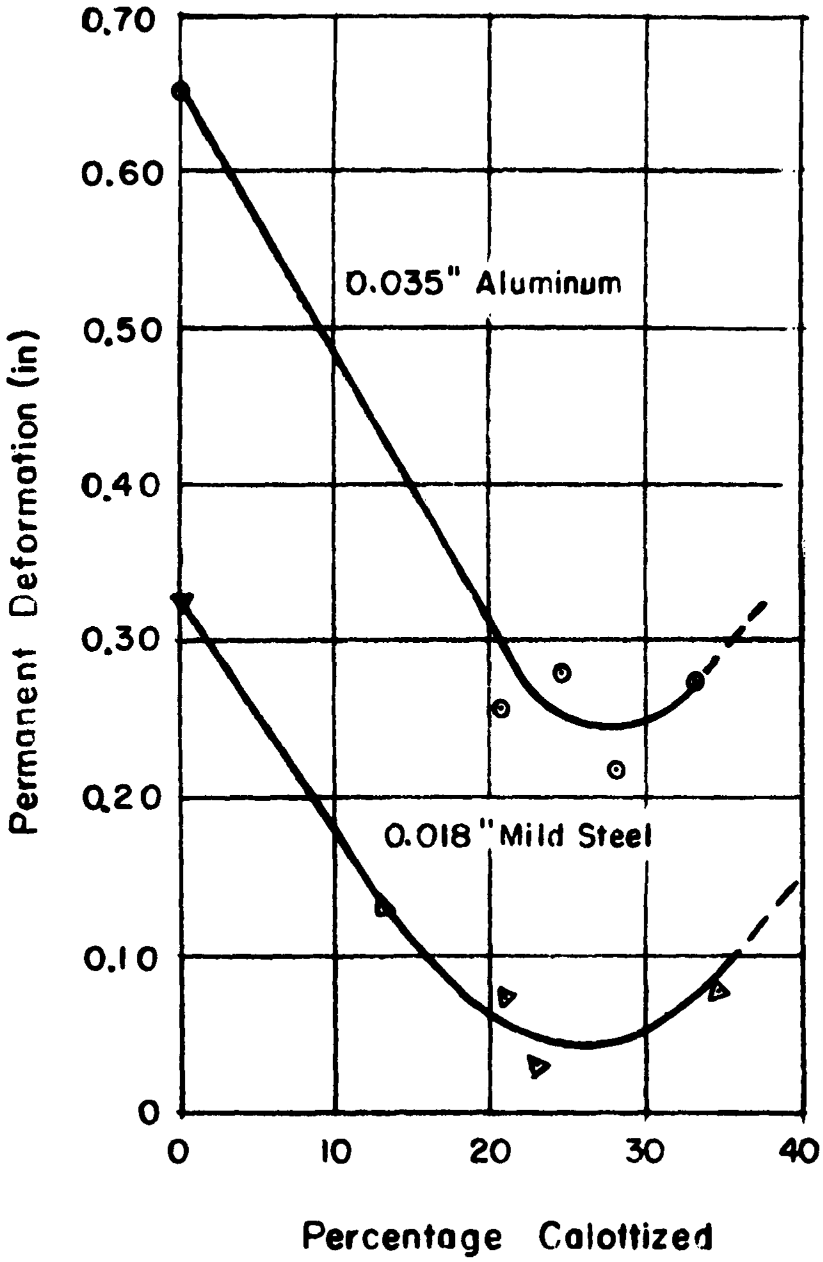

Fig. 22. Deformation from impact.

10. Vibration Frequency Tests. Limited preliminary tests were conducted to explore the vibration characteristics of calottized sheet. The resonate frequency on 13.5-inch spans of plain 0.035-inch-thick 5052 aluminum sheet and 23 percent calottized samples of the same sheet was 40 cps and 80 cps, respectively. A 6-inch test span of the calottized sheet had a natural frequency of 360 cps. It was observed during these tests that calottized aluminum sheet appears to have the ability to act as a collector or condenser and to assemble various impact frequencies and then to transmit them as a single frequency. Additional testing is needed to verify these observations. This apparent condenser characteristic of calottized sheet could be investigated by determining sound absorption coefficients using the tube method. There also appeared to be a slight change in the natural frequency with time as the vibration continued.

IV. ANALYSIS OF RESULTS

11. Deflection. Figures 13 through 21 show that calottizing single metallic sheet by cold forming increases their flexural rigidity. The influence the height of calotte (percentage calottized) has on the magnitude of the increase in rigidity becomes apparent from a study of the curves. The optimum percentage calottized for maximum rigidity as determined from these test results and shown by the peaks of the curves in Figs. 14 through 17 are:

0.018-inch steel	23 percent
0.035-inch steel	20 percent
0.059-inch steel	20 percent
0.035-inch aluminum	24 percent
0.014-inch aluminum	26.5 percent

Therefore, it appears that a practicable figure for use in production calottizing as optimum height of calotte for approximate maximum rigidity is 23 percent of the maximum plunger diameter for sheet cold formed on a die of the dimensions used in this investigation. Although not proved by these tests, it is believed 23 percent will be a practicable optimum for similar sheet calottized by cold forming on any die of like proportions such as shown in Table I.

The rigidity of optimum calottized single sheet is compared to that of plain sheet in the bar graph (Fig. 20). If the rigidity of single plain mild steel sheet is assumed to be 1 the rigidity of single calottized sheet cold formed from the same material is 14 for the 0.018-inch-thick steel sheet, 6.5 for the 0.035-inch sheet, and 3.0 for the 0.059-inch sheet. This indicates that the gain in stiffness because of cold calottizing in a given die

increases as the sheet thickness decreases. When compared on the same basis, the rigidity ratio for 0.035-inch-thick 1100-H12 aluminum sheet is 1 to 5.

Claims by the CALOTTAN representatives (par. 3) that calottized steel sheet is ten times more rigid than the plain sheet and that a two-ply combination will support 25 times the load supported by the plain sheet are misleading and useless for design as they are true only for the thinnest of the sheet range, 0.020 inch through 0.059 inch (Table I) recommended for forming in the die used in this investigation. Also, their claim that calottized sheet has "rigidity many times greater than that of any known material of this type" indicates that they are not familiar with properties of rigidized sheet produced by X Company. This is indicated by Fig. 23 where equivalent EI values determined by these tests are plotted with those for X Company rigidized sheets and by Fig. 24 which shows sheet thickness versus rigidity ratio for the two stiffening patterns. A study of the curves shows that in the areas where data are available the calottized sheet is usually a little more rigid. However, the difference in rigidity is not great.

The type of alloy and condition (hardness) had a significant effect on the stiffness of plain aluminum sheet as indicated by Fig. 16 but did not appear to have a significant effect on near optimum calottized sheet. Obviously, the rigidity ratio varied with the stiffness of the plain sheet and varies from 1/2.2 to 1/6.9 for the aluminum sheet tested.

The directional rigidity of optimum calottized cold formed aluminum sheet is shown graphically by Fig. 19. In considering this graph, recall that in producing specimens for test the sides of the square comprising the basic CALOTTAN module pattern (Fig. 6) were formed parallel to the sides of the original sheet with the top of the pattern as shown in the figure parallel to the longitudinal centerline of the sheet. Also, note that the CALOTTAN pattern is not symmetrical because the location of the calottes is different when related to the transverse instead of the longitudinal centerline. A study of Fig. 19 shows that optimum calottized sheet is most rigid and 25 percent above the average rigidity when tested parallel to the longitudinal centerline. The rigidity at angles of 45°, 90°, and 135° to the longitudinal centerline is almost equal and about 5 percent above average, and tests at intermediate angles show a rigidity generally below and some as much as 10 percent below the average. These results do not verify the claims by the CALOTTAN representatives that calottized sheet has "no preferred axes of inertia."

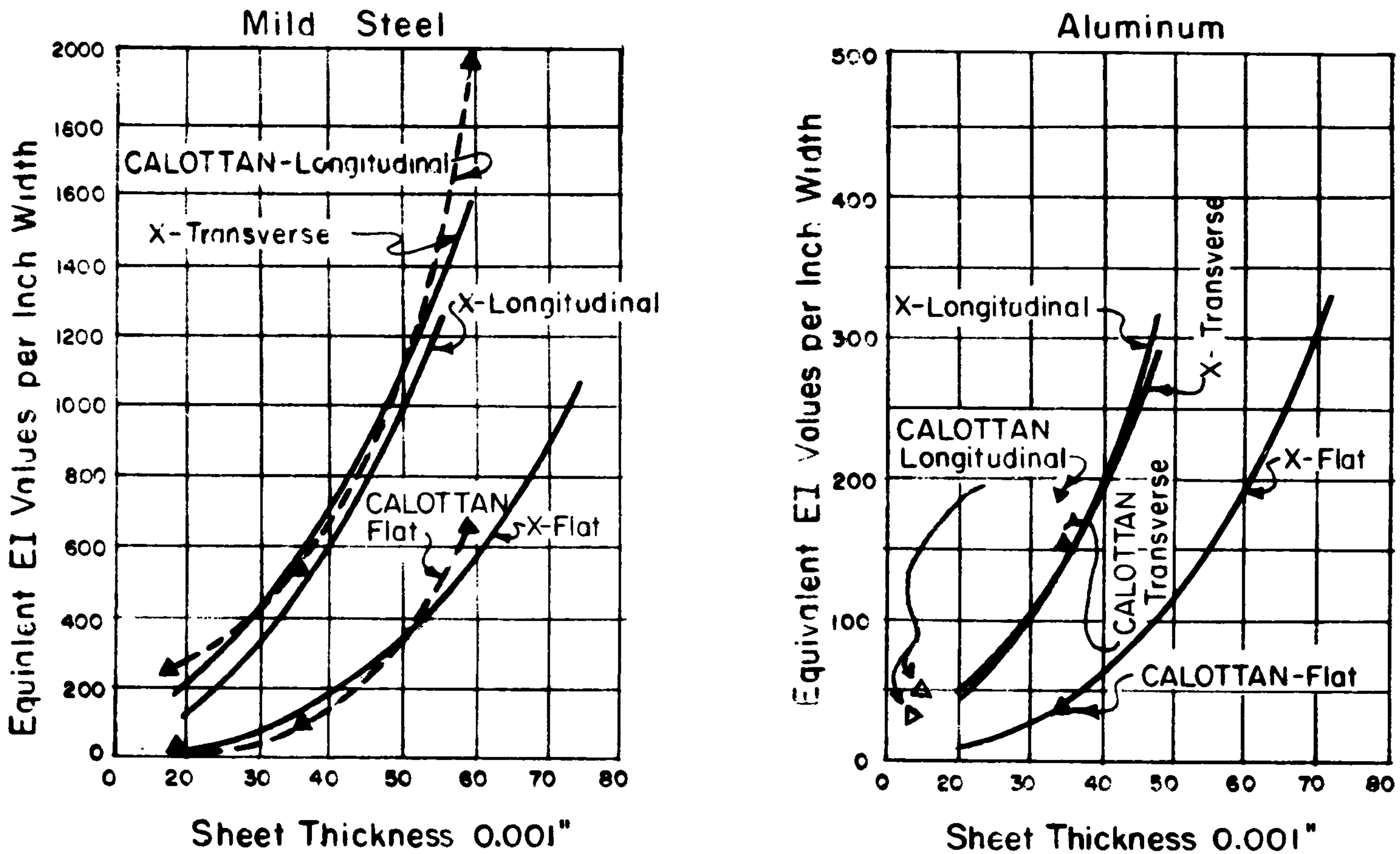

Fig. 23. Equivalent EI values of X Company rigidized vs flat and calottized material.

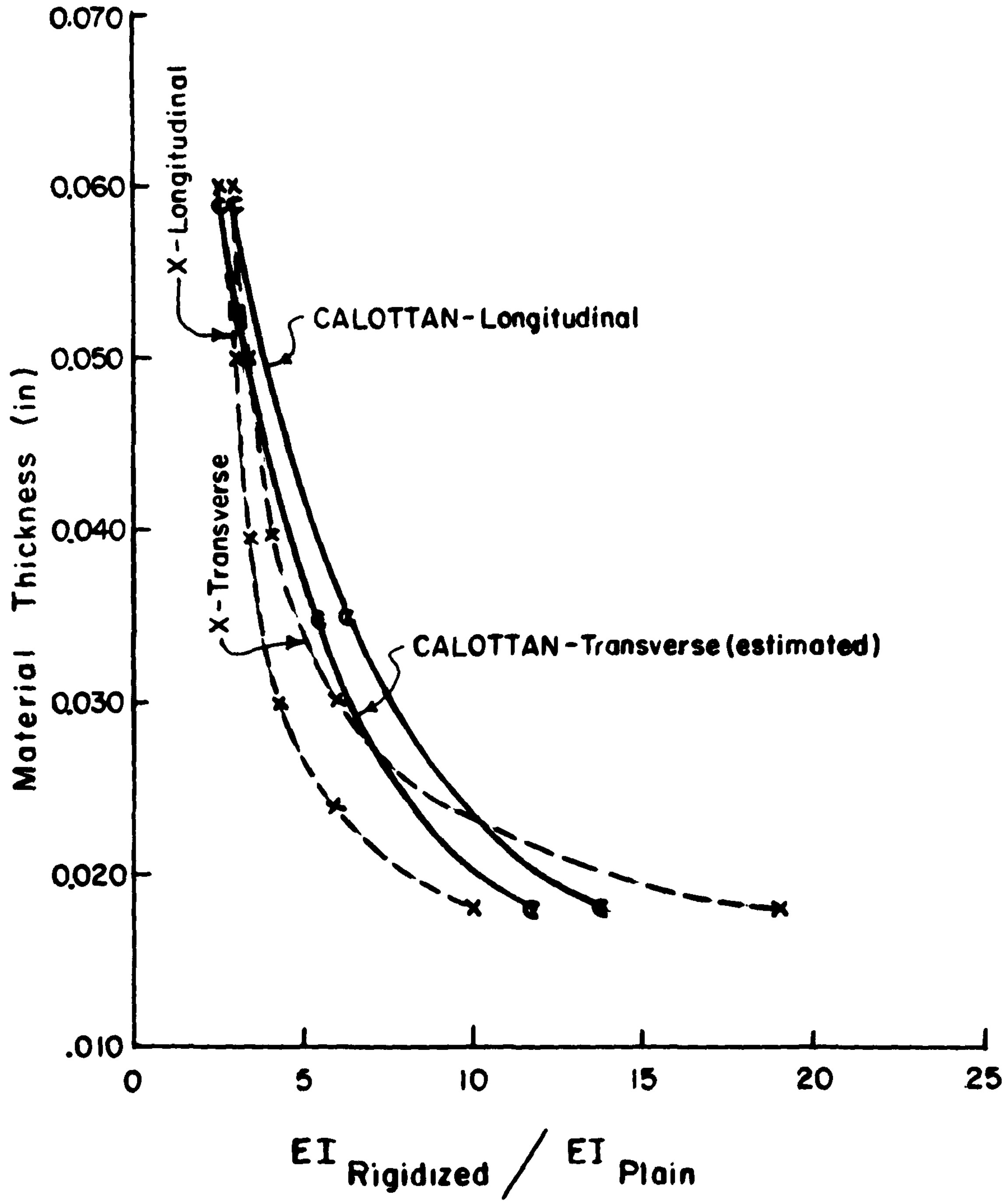

Fig. 24. Sheet thickness vs rigidity ratio for mild steel.

The rigidity of optimum calottized single and two-layer sheet is compared to that of plain single sheet in the bar graph (Fig. 21). Again, when the rigidity of a single plain sheet is assumed to be 1, the rigidity of cold formed optimum calottized two-layer steel sheet of 0.018-inch thickness is 33 and sheet of 0.059-inch thickness is 6.7. On the same basis, the rigidity ratio of two-layer 0.035-inch aluminum sheet is 1 to 13.3. The rigidity of two-layer calottized sheets is 117 percent more than one-layer calottized sheets for 0.059-inch steel, 140 percent for 0.018-inch steel, and 166 percent for 0.035-inch aluminum. As stated previously, only the results for the thinnest sheet verify claims of the CALOTTAN representatives.

12. Impact. Results of the improvised impact tests (Fig. 22) are included only to show that calottizing does improve the impact resistance of sheet materials. The magnitude of improvement indicated by these results may be questionable. The results show the impact resistance (based on permanent deflection) of 26 percent calottized 0.035-inch aluminum-alloy sheet to be 2.6 times that of the plain sheet and that of 25 percent calottized 0.018-inch mild steel sheet to be 8 times that of the plain sheet. The curves also indicate that the optimum height of calotte for resistance to impact is approximately the same as the optimum for resistance to flexure.

13. Vibration. The vibration frequency observations (par. 10) were too limited to justify quantitative deductions, but they show that calottizing metallic sheet will reduce the vibration and may have other worthwhile possibilities such as improved sound absorption. If interest warrants or requirements exist, additional testing should be undertaken to determine the possibilities of calottizing for these uses. If additional testing is done, the fatigue properties of calottized sheet should also be investigated.

14. Design. It was not possible to calculate the moment of inertia (I) for sheet formed in the complex CALOTTAN pattern, so equivalent EI values were calculated from the longitudinal deflection data obtained. These values are presented as curves in Fig. 25. The curves can be utilized to determine the stiffness to be expected from sheet of the materials and thicknesses shown. The curves cover plain sheet and sheet cold formed from zero to a little more than optimum calotte height.

In considering or using these curves (Fig. 25) we must remember that they are based upon longitudinal deflection data only. Unfortunately, no transverse deflection data were obtained for optimum calottized steel sheet, but the investigation of directional rigidity which was made on 0.035-inch aluminum calottized sheet

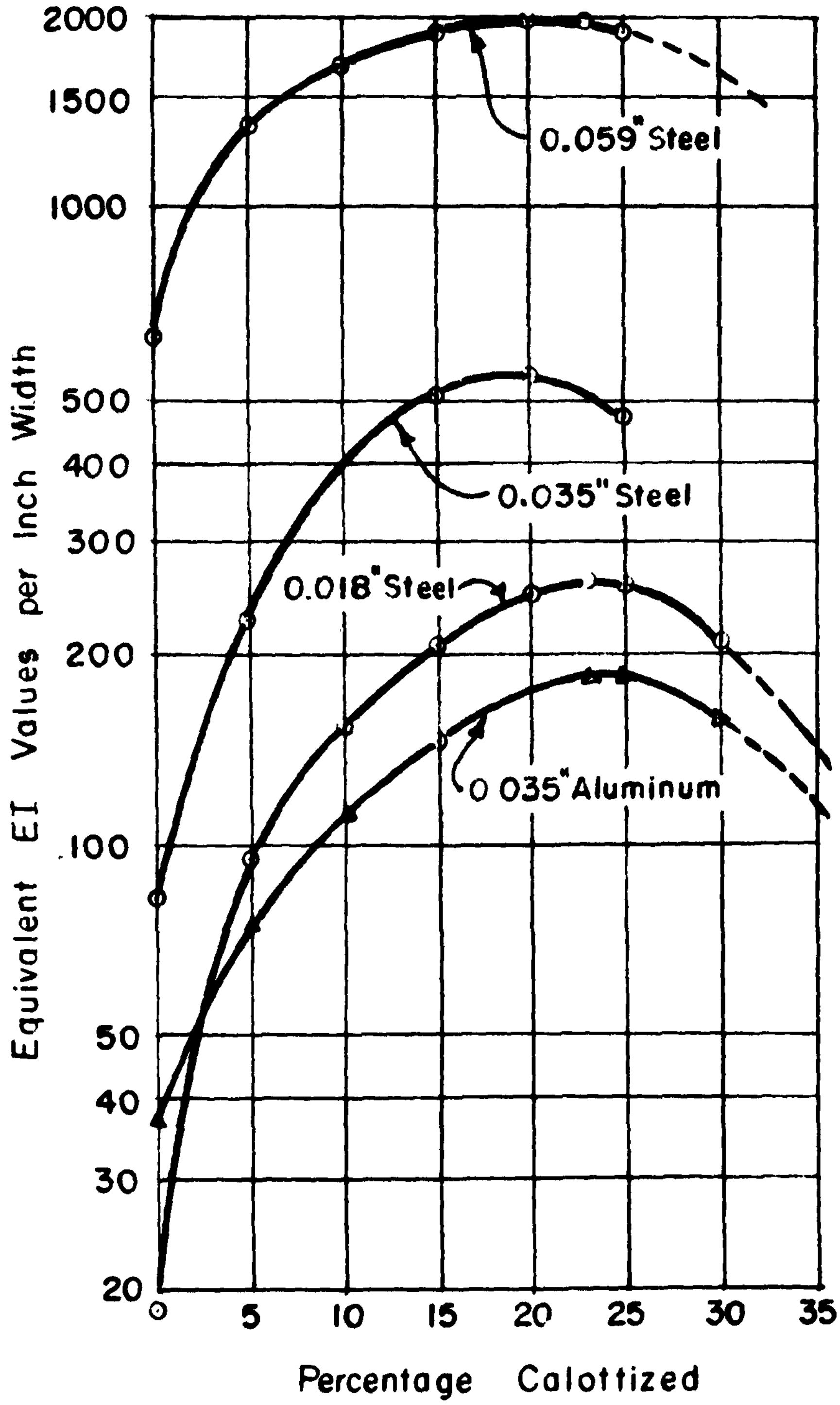

Fig. 25. Longitudinal stiffness (EI) curves for calottized sheet.

(Fig. 19) shows that the sheet carries less when loaded at angles to the longitudinal centerline. For example, 15 percent less is carried when sheet is tested at 90° to the longitudinal centerline. Accordingly, we should reduce the EI values of the curves a suitable amount as indicated by Fig. 19 when the sheet will be loaded at an angle.

Little flexural data were obtained from sheet formed to beyond optimum calotte height because they are less rigid and also the steel and aluminum sheets used in this investigation started failing in the calottes when cold formed much beyond the optimum. Table III shows typical results of our cold forming experience. It is apparent from the table that, as would be expected, the more ductile materials formed best. Note that ductile commercially pure copper sheet was satisfactorily cold formed to 80 percent calottized which was the maximum possible with the closure provided in the die. We had no experience forming heavy sheet as the die would not handle sheet much thicker than 0.059 inch but the CALOTTAN representatives furnished one sample of 0.115-inch-thick-steel sheet which was 69 percent calottized, probably by hot forming.

Table III. Results of Calottizing by Cold Forming

Material	Type	Thickness (in.)	Percentage Calottized	Remarks
Steel	HR 0.05 Carbon	0.059	27	Good; no failures.
"	"	0.035	32	"
"	"	0.018	39	"
"	"	0.018	64	Failed; few failures.
"	"	0.018	74	Failed; many failures.
Aluminum	1100-0	0.014	32	Good.
"	1100-H16	0.015	21	Good.
"		0.016	69	Failed; cracks in all calottes.
"		0.020	41	Failed; cracks in 25 percent of calottes.
"	1100-H12	0.035	33	Good.
"	1100-0	0.035	58	"
"	5052-H34	0.041	19	"
"	"	0.051	19	"
"	"	0.064	19	"
Titanium	RC-55	0.050	63	Failed; cracks in most calottes.
Copper	Commercially pure full anneal	0.032	80	Good.

Forming beyond optimum calotte height would probably not be of interest for most structural uses but would be important when adapting calottized sheet to other uses such as incorporation of insulating filler materials and other uses proposed by the developers and mentioned in par. 3. The increased surface area of calottized sheet could be advantageous for some applications and disadvantageous for others. For example, greater surface areas can be obtained for applications requiring heat transfer, but in simple stiffening applications the calottes increase the quantity of protective coatings required and may make them more difficult to apply and maintain. The additional space occupied by the increased thickness resulting from calottizing may be a problem for some applications. Joining calottized sheet and attaching such sheet to structural frames is a definite problem when compared to flat sheet and must be solved for each application when the sheet is incorporated in any design. Joining and attaching is also a problem when one considers the structural shapes which, although not tested in this investigation, are proposed by the representatives of CALOTTAN as illustrated by Fig. 26.

The study showed that up to 80 percent calottized sheet can be cold formed from properly selected materials, and it appears that sheet of any desired calotte height up to 100 percent calottized could be provided by proper selection of material and forming process if its use is found by the designer to be economically feasible.

Rigidizing metallic sheet by forming in either the CALOTTAN or X Company patterns does not change their weight, so utilization of rigidized sheet can reduce the weight of an end item as a result of the increased rigidity which allows the use of thinner and therefore lighter sheet.

15. Production. Information from the representatives of CALOTTAN indicates that calottized sheet is being produced and used in Europe. We have not been able to verify the extent of the production or use. So far as we know CALOTTAN has not been made available in the United States. Unquestionably, calottized sheet can be produced in large quantities if the demand should justify such production. All that has been produced was formed by press-forming individual sheets but our discussions with metal fabricators indicate that calottizing can probably be accomplished by roll forming and at a reduced cost if the demand should justify the expenditure necessary for such production equipment.

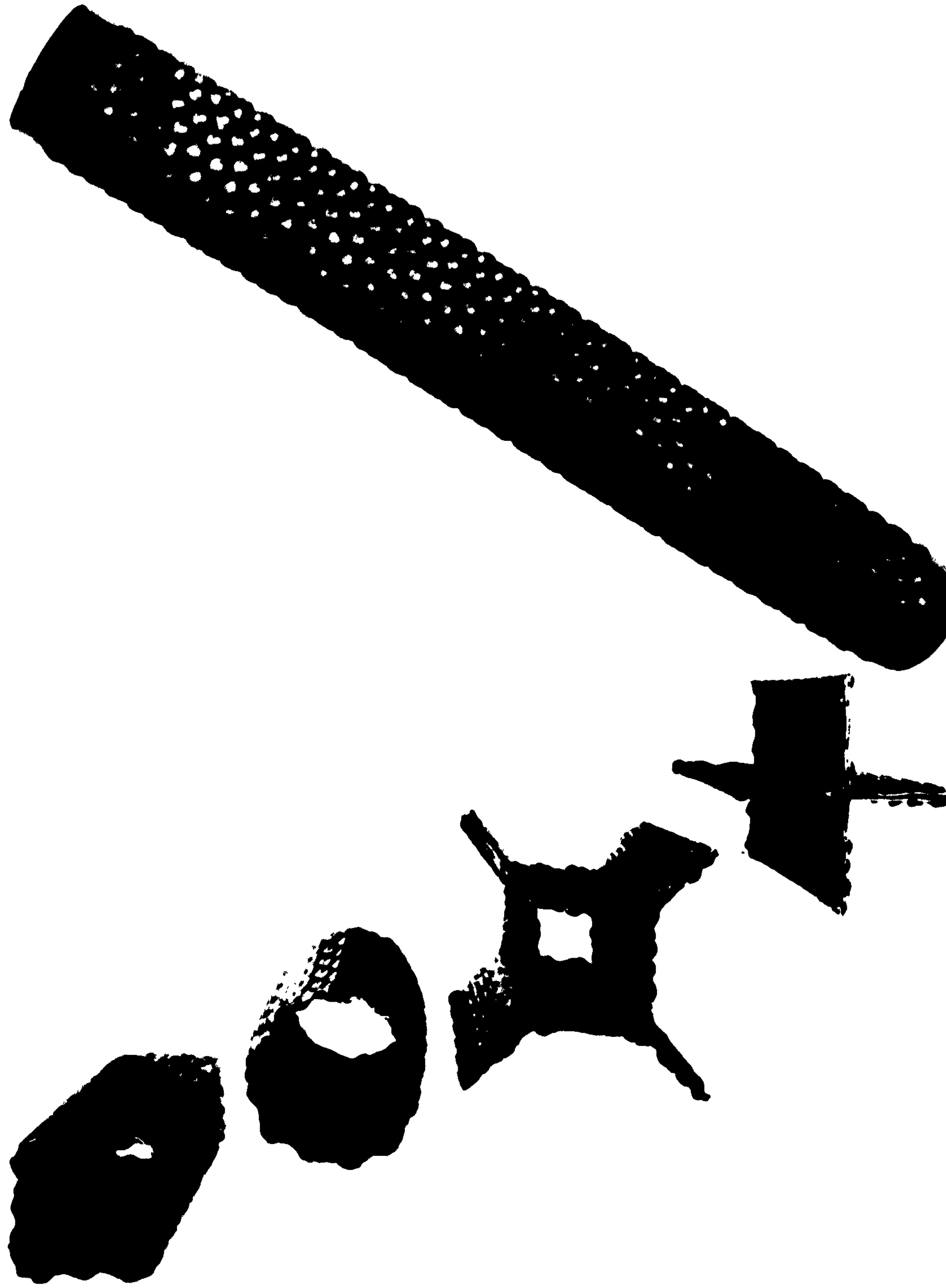

Fig. 26. CALOTTAN structural shapes.

V. SUMMARY OF RESULTS

16. Summary. The results of our investigation of the CALOTTAN process follow:

a. The stiffness of sheet materials is increased by calottizing.

b. The stiffness of single steel and aluminum sheet cold formed to optimum calotte height in the dies used in this investigation was increased over plain (flat) sheet by factors of from 3 to a maximum of 14.

c. The magnitude of the increase in stiffness caused by cold forming metallic sheet in the CALOTTAN pattern varies with the height of the calotte.

d. The magnitude of the increase in stiffness of metallic sheets of a given material as a result of optimum calottizing by cold forming in the same die, decreases as the sheet thickness is increased.

e. To obtain maximum rigidity from metallic sheet calottized by cold forming, the height of the calottes should be about 23 percent of the maximum diameter of the calotte-forming plunger.

f. The type and condition of the alloy of a given metallic material does not appear to affect significantly the stiffness of sheet optimum calottized by cold forming.

g. Calottized metallic sheet does have "preferred axes of inertia."

h. The directional rigidity of cold formed optimum calottized aluminum sheet varies up to 35 percent.

(1) Longitudinal rigidity is greatest and 25 percent above average.

(2) Rigidity at 45°, 90°, and 135° to the longitudinal centerline is about equal and 5 percent above average.

(3) The rigidity at intermediate angles is as much as 10 percent below average.

i. Metallic sheet rigidized in the X Company pattern show stiffness sometimes a little less but approximating that of similar calottized sheet.

j. The stiffness of two-layer steel and aluminum sheet cold formed to optimum calotte height in the dies used in this investigation was increased over single plain sheet by factors of from 6.7 to a maximum of 33.

k. The impact resistance of metallic sheet is improved by calottizing.

l. Up to 80 percent calottized sheet can be cold formed from selected metallic materials, and it appears that metallic sheet of any desired calotte height up to 100 percent calottized can be provided by proper selection of material and forming process.

m. Calottizing increases the vibration frequency of metallic sheet.

VI. CONCLUSIONS

17. Conclusions. It is concluded that:

a. The rigidity and impact resistance of sheet materials are increased considerably by calottizing.

b. The claim made by CALOTTAN representatives that the rigidity of sheet materials is increased ten times by calottizing is considered valid for only the thinnest sheet of the range that can be formed in the CALOTTAN die.

c. The representatives of CALOTTAN are not familiar with the properties of rigidized sheet produced by X Company. Their claim that calottized sheet has "rigidity many times greater than that of any known material of this type" is not considered valid because sheet rigidized by the X Company pattern shows stifness approximating that of similar calottized sheet.

d. Calottized metallic sheet displays preferred axes of rigidity, so the claim made by CALOTTAN representatives that calottized sheet has "no preferred axes of inertia" is not considered valid.

e. Rigidized metallic sheet materials can be used to reduce the weight of some components of Military equipment.

f. Calottized metallic sheet should be considered by designers of Military equipment on a value analysis basis when calottized sheet becomes available in the United States.

g. Rigidized sheet produced in the United States by X Company is approximately as efficient as calottized sheet, is presently available in the United States, and should be considered by designers of Military equipment on a value analysis basis.

APPENDICES

APPENDIX A

AUTHORITY

Item 2992
CETC Mtg 327

RDT & E PROJECT CARD	1. TYPE OF REPORT ☐ NEW ☐ FINAL ☒ REPLACES (No. & Date) 8-93-31-400 31 Dec 59		REPORT CONTROL SYMBOL CSCRD-1 (R2)
2. PROJECT TITLE TASK Application of Lightweight Metals in Engineer Equipment (U)		3. SECURITY OF PROJECT Unclas	4. PROJECT NO. 8S93-31-001
		5. TASK NO: 8S93-31-001-08	6. REPORT DATE 18 August 1961
7. BASIC FIELD OR SUBJECT Materials	8. SUB FIELD OR SUBJECT SUB GROUP Materials for Engineer Equipment		9. CATEGORY AR
10a. COGNIZANT AGENCY Corps of Engineers	11a. CONTRACTOR AND/OR GOVERNMENT LABORATORY USA Engineers Research and Development Laboratories, Fort Belvoir, Virginia		b. CONTRACT NUMBER
b. DIRECTING AGENCY Mil Sciences Div., R&D, OCE			
c. REQUESTING AGENCY Office, Chief of Engineers			
12. PARTICIPATION BY OTHER MILITARY DEPTS. AND OTHER GOVT. AGENCIES	14. SUPPORTING PROJECTS		18. EST. COMPLETION DATES DEV. ENGR TEST. USER TEST OPERATIONAL
13. COORDINATION ACTIONS W/OTHER MILITARY DEPTS. & OTHER GOVT. AGENCIES	15. DATE APPROVED See Item 23e	16. PRIORITY 2 / 17. BUDGET CODE 5000	19. EST. SUPPORT LEVEL ☒ UNDER \$50,000 ☐ \$50,000 - \$100,000 ☐ \$100,000 - \$250,000 ☐ \$250,000 - \$500,000 ☐ \$500,000 - \$1,000,000 ☐ OVER \$1,000,000
20. CDOG Par 612	21. SPECIAL CODES		

22. REQUIREMENT AND/OR JUSTIFICATION

The materials used in Engineer equipment under development and in the supply system should be examined for the purpose of decreasing equipment weight through increased use of lightweight metals and more efficient use of all metals. This task will result in more efficient utilization of materials and improved techniques of materials forming and joining, which will decrease logistic problems and increase performance-weight ratios.

23. Brief of task and objective

a. Brief:

(1) Objective:

(a) To study bills of material of developmental and existing engineer equipment and take steps to have revisions made as necessary to achieve maximum feasible utilization of lightweight metals and more efficient use of all metals to increase mobility and decrease weight.

(2) Technical Characteristics:

(a) Not applicable to this task. Compliance with the technical characteristics of items under review will be maintained.

b. Approach:

(1) Because of the broad scope of this task which covers all Engineer equipment and its long-range and continuing nature, the plan of approach is in two phases.

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2992/327

RDT & E PROJECT CARD CONTINUATION	REPORT DATE 18 August 1961	TASK NO. 8S93-31-001-08

Block 23 b continued

Phase I. Examination of Engineer equipment under development.

Phase II. Examination of Engineer equipment now in the supply system.

(2) Examination of Equipment items from both phases may be made concurrently, but, in general, examination of equipment under development will have priority over equipment now in the system. The order of selection of items of equipment and categories for examination in each phase will follow a priority based upon the greatest need for weight reduction from the viewpoint of the maximum over-all benefit toward decreased logistics problems with Engineer equipment.

(3) Studies will be initiated on new equipment during early stages of the development. Bills of material will be established in cooperation with personnel of the pertinent end item development task. The bills of material will be reviewed as required during the development so final selections will conform to the objective of this task.

(4) Studies will be initiated on items now in the supply system when indicated to correct deficiencies or in accordance with priorities in par. 23b(2) above as time permits.

(5) Categories of investigation may include but are not limited to modernizing technical characteristics, selecting materials to correct reported deficiencies, consideration of lightweight metals in new applications, re-examination of unsuccessful applications in light of new knowledge, review of lightweight metal applications made by others, and application of more efficient methods of utilizing all metals to obtain equal performance form lighter weight components.

(6) When desirable as a result of the investigation, bills of material will be finalized and action taken to incorporate them in pertinent drawings and specifications.

c. Tasks:
Not applicable.

d. Other Information:
(1) Scientific Research: None.
(2) References: None.
(3) Discussion: The urgent need for an item has often imposed on the project engineer the necessity of using expedients. The performance requirement has been met while logistics problems have been increased. Items developed under those conditions may be expensive, excessively heavy, difficult or impossible to transport by aircraft, and also difficult to produce, operate, and maintain. This task will correct a large number of these faults or shortcomings by materially reducing the weight, the quantity of critical materials, the cost, and other problems, and by improving the over-all military potential.

APPENDIX B

SUPPLEMENTARY INFORMATION

March 13, 1956 J. PFISTERSHAMMER **2,738,297**
HONEY-COMB-TYPE STRUCTURAL MATERIALS
AND METHOD OF MAKING SAME
Filed June 10, 1952 3 Sheets-Sheet 1

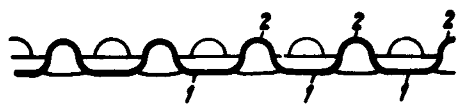

Fig.1

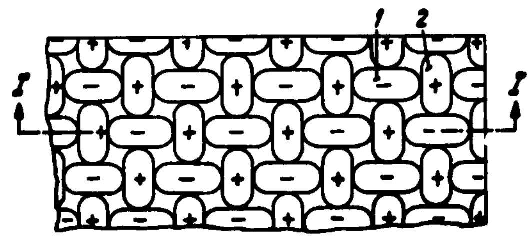

Fig.2

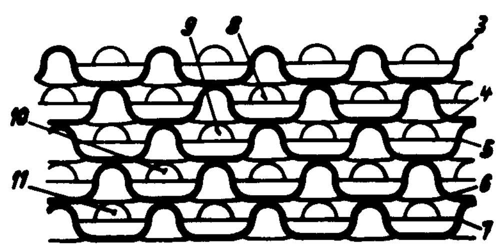

Fig.5

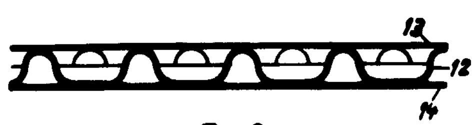

Fig.6

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March 13, 1956 J. PFISTERSHAMMER **2,738,297**
HONEY-COMB-TYPE STRUCTURAL MATERIALS AND METHOD OF MAKING SAME
Filed June 10, 1952 3 Sheets-Sheet 2

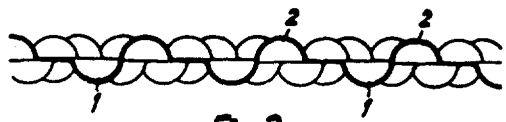

Fig. 3

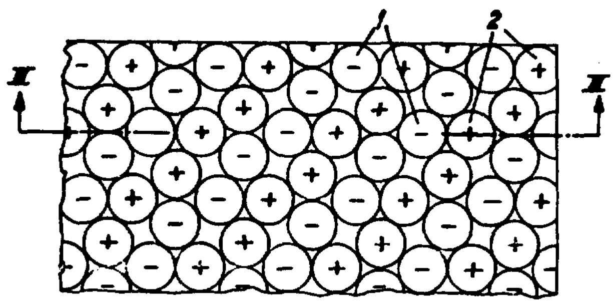

Fig. 4

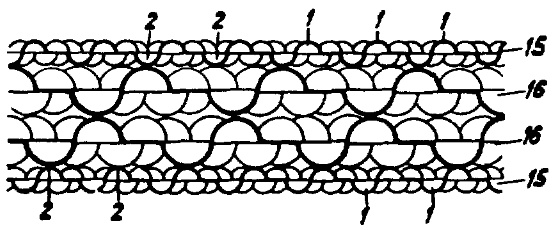

Fig. 7

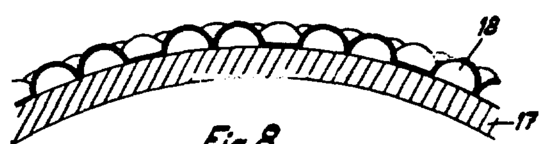

Fig. 8

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March 13, 1956 J. PFISTERSHAMMER 2,738,297

HONEY-COMB-TYPE STRUCTURAL MATERIALS
AND METHOD OF MAKING SAME

Filed June 10, 1952 3 Sheets-Sheet 3

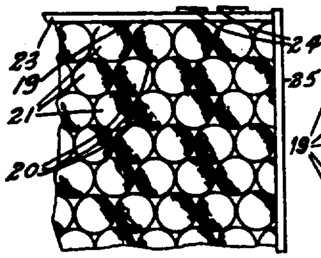

Fig. 9

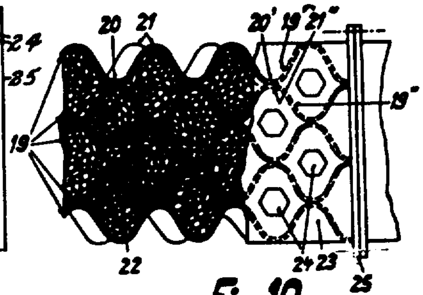

Fig. 10

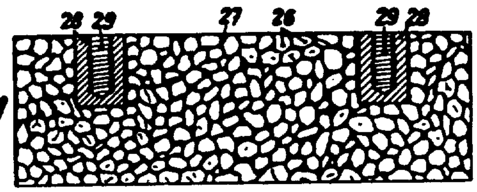

Fig. 11

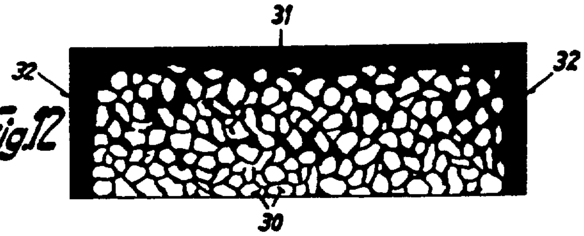

Fig. 12

Fig. 13

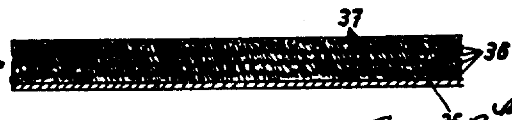

Fig. 14

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United States Patent Office 2,738,297 Patented Mar. 13, 1956

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2,738,297

HONEYCOMB-TYPE STRUCTURAL MATERIALS AND METHOD OF MAKING SAME

Joseph Pfistershammer, Dietikon, Zurich, Switzerland

Application June 10, 1952, Serial No. 292,759

24 Claims. (Cl. 154—52.5)

The present invention relates to new structural materials. The structural materials according to this invention have a lattice-like form and consist at least in part of a component of great strength and ductility (basic material) such as steel, aluminum and the like, or a synthetic material of suitable nature, such as a polyamide, at least part of the basic material being formed in such a manner as to provide curved lines of stress in every direction of stress of the structure.

Such structural materials are employed, for example, in the construction of coverings for vehicles of all kinds, as well as for roofs, walls, floors, ceilings, boilers, containers and the like. The structural material according to the present invention is characterized by its high elastic deformability in all directions of stress. To this end, the basic material is formed so as to provide curved lines of stress, preferably in every direction of stress.

Embodiments of the structural material particularly suited for the purpose of this disclosure consist of a basic material whose entire surface is formed by closely adjacent elevations, or both depressions and elevations so that the structure is fully curved in every principal directions of stress.

For particular applications, it has been found advantageous to employ a second material when producing the structure in addition to the aforementioned basic material. The second material should possess a high degree of hardness and high heat resistance, such as material of a mineral nature. This second material is enclosed as a filling material within hollow spaces provided by the basic material. Such filling material may consist of granular, comminuted or, preferably, spherical particles.

The novel features which I consider characteristic of my invention are set forth with particularity in the appended claims. The invention itself, however, and any additional objects and advantages thereof will best be understood from the following description of several preferred embodiments when read in conjunction with the accompanying drawings, in which:

Figs. 1 and 2 are diagrammatic sectional views illustrating the principle incorporated in structures of the present invention, Fig. 1 being a sectional view on the line I—I on Fig. 2;

Fig. 3 is a sectional view taken on the line III—III of Fig. 4, both showing a construction in which the depressions and elevations are formed and arranged differently from those shown in Figs. 1 and 2;

Fig. 5 is a sectional view of a first embodiment of a structure made up of basic material;

Fig. 6 is a sectional view of another embodiment of a structure made up of basic material;

Fig. 7 is the embodiment of a structure wherein, according to the invention, laminations of different basic materials are employed;

Fig. 8 is the embodiment of a curved structure made according to this invention;

Figs. 9 and 10 are front and end views, respectively, of a structure (partly shown in section in Fig. 10) and

2

consisting of basic materials and a filling material according to the invention, is inserted within the hollow spaces of the basic material;

Figs. 11 and 12 show two different embodiments of the invention wherein a filling material has been cast into the basic material;

Fig. 13 is an embodiment of a structure according to the invention wherein the components of the structural material are pressed together by lamination; and

Fig. 14 is the embodiment of a structure formed by spraying component parts onto a mold.

The structural material diagrammatically illustrated in Figs. 1 and 2 is provided, throughout its area, with closely adjacent depressions and elevations 1 and 2 respectively. These depressions and elevations are of elongated shape and are alternately vertically offset against each other. In order to clearly understand the principle applied, the depressions have been marked "—" and the elevations "+" in Fig. 2. As may be seen, this structural material possesses only curved lines of stress in every principal direction of stress. The plan view of Fig. 2 particularly shows that, because of the arrangement of the depressions and elevations 1 and 2, respectively, the lines of stress obtained are curved to a higher or lesser degree. Alternatively, such elevations and depressions may be circular instead of oval, and be pressed into a plate in the shape of hemispheres.

In a preferred arrangement of hemispherical domes in pairs, the edges of the domes touch in the direction of the common center line, so that the common center lines of adjacent pairs of hemispheres are normal to each other and intersect at the point of contact between two paired hemispheres, as appears from Figs. 3 and 4. It is understood that all depressions and elevations need not be of identical size and shape, and, particularly for laminations used individually or on the outside, depressions or elevations may be used alone.

Fig. 5 shows a structural material comprising, in parts 3 to 7, a plurality of elements shown in Figs. 1 and 2, assembled in such a manner that the depressions of one element and the elevations of the adjacent element engage each other. Parts 3 to 7 of the structural material may be welded or riveted together at their points of contact. However when made from materials such as plastic, the multiple elements may be produced together in a single casting. The lattice work making up the structure produces a plurality of closed hollow spaces 8–11, whereby high resistance is attained against penetration of structures of this type. Moreover, such structures are largely heat and sound proof.

In many cases structural material must possess a smooth exterior surface in case of coverings for vehicles, etc. To this end, the structure may be covered, at least on one side and vertically to the principal directions of stress, by a material having a smooth surface instead of the afore-described depressions and elevations.

Fig. 6 shows such a structure comprising an element 12 similar to the elements 1, 2 shown in Figs. 1 and 2, and having flat plates 13 and 14, respectively, affixed to the two sides thereof. The structure possesses fully curved lines of stress transversely to principal directions of stress only, while comprising straight lines in the directions of minor stress. According to an additional feature of the invention, sheets may be assembled whose dome-shaped elevations or depressions and elevations differ in size and spacing, provided that the number of the depressions and elevations in one sheet is an even multiple of those in the other sheet. For example, the depressions and elevations of the outer sheet may have a size and be arranged at a distance of one-third to one-half of those of the intermediate sheets.

Fig. 7 shows an embodiment wherein the spacing be-

tween the elevations and depressions 1 and 2, respectively, of the outer sheets 15 is only one-half of that of the intermediate sheets 16. Such structures are suitable, for example, as surface to be walked on (floors). The interior sheets are provided with comparatively large depressions and elevations, respectively, while the outer sheets have small depressions and elevations the number of which is an even multiple of the larger depressions and elevations. The depth of the depressions and elevations in the outer and inner sheets, respectively, may vary as well, as appears from the example shown in Fig. 7. The dome-shaped elevations may also be disposed on one side only in order to prevent or render more difficult the catching of water or dust if the structure is employed, say, as a roofing material. Structures with elevations disposed on one side only may, however, also be employed for protecting jackets of boilers, or for containers and the like.

Fig. 8 shows the manner in which a boiler wall 17 is reinforced with a structure having elevations on one side only.

The structural material shown in Figs. 9 and 10 comprises a plurality of laminations 19 of the basic material. As shown in detail in Fig. 10, these laminations are provided with closely adjacent depressions and elevations 20 and 21, respectively, distributed over the entire surface and assembled in such a manner that the depressions 20 of, say, the sheet 19', overlie the elevations 21" of the adjacent sheet 19". The sheets are welded together at their points of contact. The hollow spaces formed between adjacent sheets are filled with mineral matter 22 consisting of granules of preferably uniform size. Openings provided in the end plate 23 welded to the sheets permit entry and removal of the filling. If not in use, these openings are closed by means of screw plugs 24. A flange 25, welded to another end plate, permits connection between the end plate and other, similarly constructed plates, as illustrated in Fig. 10. If, for example, the shaped structure shown is to be used as an armor plate consisting of steel laminations totaling 35 cm. in thickness, the individual laminations may be approximately 1.5 cm. thick while the size of the filling material granules should average 2 cm.

Fig. 11 illustrates a plate structure wherein the mineral filling material 26 is cast into the basic material 27 in the form of granules of varying dimensions. The volumetric ratio between the filling material and the basic material (filling coefficient) is practically uniform throughout the entire body. Connecting members 28 with screw threads 29 are cast into the structure for attachment to other similar structures or for fastening other elements to the structure. It will prove advantageous in certain cases to cast parts of a machinable material into the structure and to machine them, subsequent to the casting, for the particular function they are to serve.

Thin-walled shaped bodies may, obviously, contain only small-size granular filling material, which is preferably mixed into the basic material prior to casting.

The filling material 30 is cast into the basic material 31 of the structure illustrated in Fig. 12. However, the filling coefficient, on the assumption that the particular body will be subject to bending stresses, is locally adapted in such a manner that the basic material is concentrated in the zone of tension (top) while the filling material is concentrated in the zone of pressure (bottom). The marginal zones 32 of the plate contain no filling material in order to enable the plate to be welded to other plates, etc.

The plate illustrated in Fig. 13 comprises a plurality of sheets 33 of the basic material pressed together with intermediate layers of filling material 34 therebetween. The thickness of the sheets corresponds to the average size of the granules.

The plate structure illustrated in Fig. 14 comprises a mold 35 on which the basic material 36 and an arenaceous filling material 37 are sprayed in several alternating layers.

Plates or parts made of the new structural material and comprising one or several laminations permit an easy and extremely firm connection in overlapping relation. The tips of the depressions and elevations of one plate engage similar depressions and elevations of the adjacent plate and are held in this position by conventional means, cementing alone producing bonds of high tensile strength with thin laminations of thicknesses up to 1 mm.

A further advantage of the herein-described structural material over ferro-concrete structures which has not been previously mentioned, is that such structures, particularly if made by means of casting, may be used immediately while concrete takes a considerable time to set. Moreover, structural material of the herein-disclosed type, say in form of bearing pillars, utilizes the compressive strength of hard broken stones, quantitatively their most important component, permitting a load of up to 4000 kg./cm.^{2}, while in the case of concrete pillars the same material can be utilized only up to the compressive strength of the cement binder, viz. a load of approximately 300 kg./cm.^{2}.

Any given weight of the new structural material, with or without filling material, combines a maximum of elasticity with a maximum of admissible load. It withstands great and sudden temperature changes without the dangerous internal stresses resulting in cracks, and it acts as a highly efficient insulator against temperature differentials, sound and vibration. Moreover, it is practically rupture-proof, even under great deformation stresses.

The structures according to this invention may be employed as structural elements or be formed directly into shaped bodies. For example, bodies of plate-like, dome-like, pillar-like, tubular or boiler-like shape may be made therefrom. Entities, including high-pressure boilers, made from material according to the invention are free from internal stresses in any dimension, irrespective of whether they have been produced by rolling or casting operations. Even frozen boilers or radiators, when thawed, will not crack but expand elastically and resume their former shape. Various alterations in respect of the structure of the said shaped bodies, the type of the material employed and special constructional features may be effected without departure from the scope of the invention.

One of the preferred uses of structural material according to this invention is that of producing armor surfaces. With the constant development of projectiles and explosive charges the demands made on armor plate are gradually increasing. Various means have been devised of increasing the impact resistance of armor plate without further addition to the thickness of the plate. Generally speaking, the action of a flat plate extending normally to the direction of a projectile may be compared with the action of a taut rope subjected to a stress intermediate the points of suspension. The more taut the rope, the greater will be the stress caused by a given load or, expressed differently, the stress will be reduced proportionately to the resiliency of the rope and the danger of rupture will be similarly reduced in case of a resilient rope. In view of this, an armor plate should be constructed in such a manner that every section subject to the impact of a projectile is resilient in every conceivable direction of approach of the said projectile. According to the present invention this object is attained. Such armor plate may be of a construction similar to the corrugated diaphragm of an aneroid barometer. It was found particularly advantageous to shape the depressions and elevations as domes, or hollow hemispheres. In order to produce armor plate with the necessary rigidity it is advisable to build up several sheets of the described structure into a laminated body, and to dispose the sheets in such a manner that the depressions of one sheet overlie the elevations of the adjacent sheet, the points of contact being connected by welding or riveting, or by casting the entire structure in one piece.

Rigid armor plate may be constructed in this manner

having a resiliency far superior to that of a flat armor plate. Nevertheless, the plate, as a whole, has far greater rigidity and bearing strength than conventional armor plate. Experiments have shown that the impact resistance of armor plate constructed according to this invention, when using identical quantities of basic material is a multiple of that of conventional armor plate. Apart from the reasons outlined above, the superiority of armor plate according to this invention resides in the fact that the section hit by the projectile is not scattered at the point of impact as is the case of conventional armor plate but, due to its curved shape and resilient character, drastically resists the impact of the projectile. It is obvious that the exterior shape of the armor plate also increases the likelihood of deflection of the projectile.

The mineral filling material disposed in the hollow spaces of the armor plate serves a number of purposes. Principally, it is called upon to slow down the entering projectile. It is, therefore, advantageous to employ a filling material possessing a high degree of hardness and a high coefficient of friction. The material is, of course, crushed by the entering projectile, but it thus consumes the kinetic energy of the projectile and resists the further penetration of the projectile in a high degree. The pressure which the projectile exerts upon the armor plate is thereby scattered in a wide-angled cone so that the kinetic energy of the projectile is distributed over a considerable area which is resilient and increases as penetration progresses. It is not advisable to cast concrete into the hollow spaces because concrete would constitute a rigid component having a large moment of inertia. Moreover, concrete is too soft and, being devoid of hollow spaces between individual particles, fails to oppose the transmission of heat or to disperse the flash. For this reason the filling material within hollow spaces is preferably granular. A high filling coefficient may be achieved by means, such as vibrators. A further function of the filling material is to reduce the fusing action of certain projectiles, particularly projectiles with hollow charges. For this purpose the filling material preferably possesses a higher melting point, and a thermal conductivity several times lower than that of the basic material. These conditions are fulfilled for example, by a combination of steel and steatite or corundum as the melting point of the latter material lies far above that of steel. An armor plate of the above described construction is suitable for any type of armor both for armored cars (tanks) and ships, in particular submarines, and for aircraft, gun shields, fortresses, shelters and the like.

In many cases of metal construction, and particularly steel constructions of all kinds, low weight structural materials or structural elements are required which, nevertheless, possess the strength and heat resistance of conventional materials. Structural materials of this invention comply with these requirements. The basic material suitable in such cases is a metal, most frequently steel, which lends the element the necessary strength (tensile and bending strength), while as filling material pebbles may be used whose specific weight is considerably lower than that of the basic material, such as steel. Aluminum alloys of which some are comparable to steel in respect of tensile strength are particularly suitable for use as basis material owing to their small weight.

If the structure is not required to be highly heat resistant, non-metallic materials, such as plastics, may serve as basic materials. The polyamides known under the trade names of Nylon and Grilon were found to be suitable in lieu of steel.

The demands made on the filling material may vary widely according to the use to which the material is put. In general, materials possessing great hardness and high compressive strength, such as quartz, particularly hard basalt, silicon carbide and corundum, will be preferred. For special uses hard glass, hard porcelain, steatite or the like may be used as filling material. It is obvious that the filling material may be a mixture of various mineral substances. For structures and structural elements exposed to high heat, filling materials will be preferable whose melting point is higher and whose heat conductivity is lower than that of the basis material.

In order to replace structural materials, e. g., steel or concrete, by a structural element of the kind described possessing lesser weight and higher strength respectively, certain limits must be observed in respect of the mechanical strength of the individual components. It may thus often be found advantageous to employ a basic material possessing a tensile strength of not less than 4000 kg./cm.^{2}. The realizable values are approximately 8000 for steel, 4500 for certain aluminium alloys and approximately 4500 kg./cm.^{2} for nylon. On the other hand, the filling material should have a tensile strength of not less than 4000 kg./cm.^{2} and a hardness of at least 7 (Mohs' hardness), values that may be attained with materials such as quartz and corundum. All disadvantages inherent in the basic material if applied alone, such as great weight, insufficient heat resistance, high heat conductivity, and high price of the basic materials, and low tensile strength (usually below 800 kg./cm.^{2}) concomitant with brittleness of the filler, may be substantially eliminated by the herein disclosed combination of the two components.

As far as the shape of the structural material is concerned, any shape and form may be produced. The structure may be a hollow body consisting of the basic material in which the interior space is filled with filling material in coarsely or finely granular form. It is advantageous in many instances to subdivide the interior space into a plurality of hollow spaces.

A further embodiment of the work material according to my invention has the filling material cast into the basic material. Casting is preferably effected under pressure, such as a pressure of 10 atmospheres, so that the mineral inclusions are pre-tensioned. The object can be attained by working with heated materials. The basic material usually contracts to a greater extent on cooling or solidification than the filling material, so that the latter is compressed upon cooling.

The applications of cast structures of this type are practically unlimited. With steel as the basic material, the structural element can replace an element made of steel alone in almost all practical cases since the lattice-like structure provides a mechanical strength practically identical with or only inconsiderably lower than steel. Moreover the saving in weight and costs which may reach 50 per cent and more, the reduced heat conductivity and, in certain cases, the increased heat resistance are of greatest importance. The use of an aluminium alloy as basic material enables a further weight reduction.

Such structures may, for instance, be adapted as elements in the construction of at least part of the hull of a ship or aircraft. The saving in weight has a very favorable effect on the energy required for the propulsion of these and other vehicles. Plate-like bodies may be manufactured for use as structural elements for certain floor finishes. Road surfaces and runways for aircraft embodying the present invention are much less subject to wear and tear than similar structures made of concrete or gravel. In addition, due to the presence of the mineral filling material, which should be present in large amounts for such purposes, such surfaces have a far better "grip" than steel runways, for instance. Moreover, decorative floors, window-cases and doorposts may be made of the material. In order to enhance their attractiveness, regularly shaped stones of identical or different colors arranged in mosaic may be used on the surface while the non-ferrous metal used as basic material is made visible at the joints. The cast body may also be designed as an explosive charge, a nonmetallic material serving as basic material in certain cases. This is of particular advantage if the explosive charge is a mine because, due to the absence of metallic components, it cannot be de-

tected by means of the usual mine detectors. Structural material of this type is of particular value in the construction of safes. It is practically impossible to destroy by means of welding torches safes made of this material. Finally, structures according to the present invention can be used as poles or at least as parts thereof. Poles so constructed (e. g. poles for electric transmission systems) will prove far more resistant against the effects of the weather, e. g. sand storms in deserts, than poles made of steel or concrete.

According to a fundamentally different embodiment of the present invention, the filling material is pressed together between sheets of the basic material, in layers of a thickness comparable with the size of the granules. Structures of this type are preferably produced by means of a rubber plunger in order to achieve an intimate juncture of the components. In addition, a binding agent with high binding power, such as a cellulose binder, may be used to bind the sheets and the filling material. Furthermore, the sheets may be connected by means of rivets, screws or by welding at predetermined points and around the edges. This embodiment is particularly suited to the manufacture of helmets akin to steel helmets, the preferred material for the sheets of approx. 1.0 mm. thickness being a material of lesser weight, such as plastic. The most suitable filling material is quartz sand whose granules should, for this purpose, be of a diameter of approximately 1 mm. Of course the application of the structures of the kind described is not restricted to the above-mentioned example.

Comparable to cast structures is an embodiment wherein the basic material and the filling material are applied on a mold in alternating coats. The mold may constitute part of the structure or merely serve for the manufacture thereof. The components may, for instance, be sprayed upon the mold, but the application of the components to the mold may also be effected by dipping. In either case, the filling material must be applied prior to the solidification of the basic material in order to ensure perfect inclusion of the filling material between continuous layers of the basic material. This embodiment of the invention is particularly adapted to the manufacture of thin-walled bodies, such as thin armor plate, steel helmets and the like. Complete armoring of armored cars, ships and the like, but also individual armor shields or steel helmets may be reinforced subsequent to manufacture and adapted to increasing demands made upon them. Damage caused to armor of all types by hits or other causes may be easily and satisfactorily repaired as well as the metallic wall elements of vehicles, structures and bodies of all kinds exposed to extraordinarily severe weather conditions such as sand storms, sea water and the like, or if their strength and durability is to be increased for any reason.

I claim:

1. A structural material comprising a sheet member covered over substantially the entire utilizable sheet area with elevations which all have a curved cross section in every direction of the sheet plane and are arranged so that no more than two of said elevations are in alignment with each other in one given direction of stress.

2. A structural material comprising a sheet member covered over substantially the entire utilizable sheet area with elevations and depressions which all have a curved cross section in every direction of the sheet plane and are arranged so that no more than one of said elevations and said depressions are in alignment with each other in one given direction of stress.

3. In a structural material according to claim 2, said curved elevations and depressions being immediately adjacent to each other in different coordinate directions of the plane of the sheet so that all lines of stress are curved in every direction of stress.

4. A material according to claim 2, characterized by the fact that the sheet member is provided throughout its area with closely adjacent depressions and elevations so that all the lines of stress are curved in every principal direction of stress.

5. A structural material comprising a number of laminations, each lamination consisting of a sheet member covered over substantially the entire utilizable sheet area with elevations and depressions which all have a curved cross section in every direction of the sheet plane and are arranged so that no more than one of said elevations and said depressions are in alignment with each other in one given direction of stress, said laminations being formed so that the depressions of one member at least partly overlie the elevations of the adjacent member.

6. A material according to claim 5 characterized by the fact that at least two laminations possess a different number of depressions and elevations.

7. A material according to claim 6 characterized by the fact that at least one exterior lamination possesses a larger number of depressions and elevations than the interior laminations.

8. A material according to claim 6 characterized by the fact that the number of depressions and elevations in one lamination intermediate of two points of contact is an even multiple of the number of depressions and elevations in the other lamination.

9. A material according to claim 5 characterized by the fact that at least two laminations possess depressions and elevations of different size and shape.

10. A material according to claim 5 characterized by the fact that the said members are cast integrally.

11. A material according to claim 1 characterized by the fact that at least one of its surfaces vertical to the principal directions of stress is covered by a material with a flat surface.

12. A material according to claim 1 characterized by the fact that a mineral filling material is disposed in the hollow spaces of the member.

13. A material according to claim 12 characterized by the fact that the filling material is granular.

14. A material according to claim 1 characterized by the fact that said sheet member as a whole has a curved shape.

15. The method of producing a honeycomb-type structural material, which comprises forming sheets of laminations each having substantially the entire sheet area covered with elevations which all have a curved cross section in every direction of the sheet plane and are arranged so that no more than two of said elevations are in alignment with each other, joining a plurality of said laminations together in face-to-face relation having said elevations of one lamination placed in registry with respective elevations of an adjacent lamination whereby hollow spaces are formed between said laminations, and filling said spaces with granular filler substance.

16. A material according to claim 12 characterized by the fact that the volumetric ratio between the material of said sheet member and the filling material is substantially uniform throughout the structural material.

17. A material according to claim 12 characterized by the fact that the volumetric ratio between the material of the sheet member and the filling material is locally varied and that a larger proportion of sheet material is concentrated in zones of tension and a larger proportion of filling material is concentrated in zones of pressure.

18. A material according to claim 17 characterized by the fact that means are provided for connecting the structural material with other materials or elements, that the said means for connection are cast into the structural material and consist of a material allowing subsequent machining.

19. A material according to claim 12 characterized by the fact that the filling material in thin layers is pressed

together with the member and that the connection is strengthened by a binding agent or cement.

20. A material according to claim 15 characterized by the fact that the material of the member and the filling material are applied to a carrier in alternating layers.

21. A material according to claim 20 characterized by the fact that the components are sprayed on to the carrier.

22. A shaped body made of material according to claim 1 characterized by the fact that it is formed as a stress-free and self-supporting shell.

23. A shaped body made of material according to claim 1 characterized by the fact that it is formed as tubular pole-shaped structure.

24. A shaped body made of material according to claim 1, characterized by the fact that it is formed as a curved body and that it consists of a synthetic plastic.

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APPENDIX C

PATENT LICENSE

THIS LICENSE, given this 29th day of August 1958 by JOSEPH PFISTERSHAMMER of Dietikon, Zurich, Switzerland, Licensor (hereinafter called INVENTOR) in favor of the UNITED STATES OF AMERICA Licensee (hereinafter called GOVERNMENT).

WITNESSETH THAT:

WHEREAS, to aid the national defense and promote the common welfare, numerous patent owners have, voluntarily offered, or upon request of GOVERNMENT granted, and are continuing to grant royalty-free licenses and releases to GOVERNMENT to practice the inventions secured by their patents and applications for patents (hereinafter called "such inventions"); and

WHEREAS, GOVERNMENT has utilized many such inventions for the purposes aforesaid and is desirous of obtaining further royalty-free licenses and releases including this license and release; and

WHEREAS, INVENTOR has invented a Honeycomb-Type Structural Materials and Method of Making Same covered by United States Patent Office Patent Number 2,738,297 issued March 13, 1956.

NOW, THEREFORE, in consideration of the premises and of the grant by other patent owners of licenses and like releases to GOVERNMENT, INVENTOR has agreed as follows:

ARTICLE 1. License. INVENTOR agrees to and does hereby assign, grant and convey to GOVERNMENT an irrevocable, non-exclusive, non-transferable, and royalty-free, license under the hereinbefore identified patent to practice and cause to be practiced for GOVERNMENT any and all of the inventions thereof in the manufacture, use and disposition of any article or material, and in the use of any method, in accordance with law, for a maximum of 25 tons regardless of shape, form, thickness or width of the structural materials as identified in said patent.

ARTICLE 2. Term. The license hereby granted shall remain in full force and effect for the full term of the above identified patent, or upon any substitutions or continuations thereof.

ARTICLE 3. Non-Estopped. INVENTOR agrees that GOVERNMENT shall not be estopped at any time to contest the enforceability, validity or scope of, or the title to, any patent or patent application herein licensed.

ARTICLE 4. Heirs and Assigns. This license shall be binding upon INVENTOR, heirs and assigns.

IN WITNESS WHEREOF, INVENTOR has executed this agreement as of the day and year first above written.

JOSEPH PFISTERSHAMMER

WITNESSED BY:

Category 12 - Materials

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TITLE Investigation of CALOTTAN Sheet Stiffening Process

DATE OF REPORT 24 Oct 62 TASK 8S93-31-001-08 CLASSIFICATION Uncl.

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